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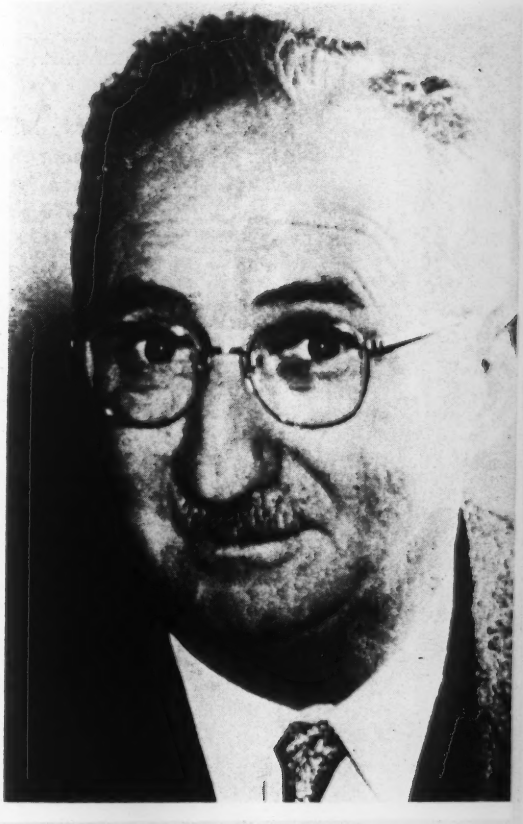


Dr. Leonard Greenburg

(See page 92)

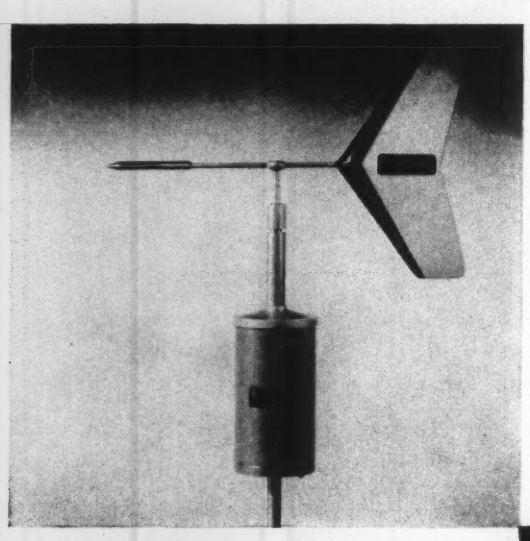
February 1960
Vol. 10, No. 1

Parts I, II

FOR SYSTEM APPLICATION

Climate Survey

Wind Transmitters



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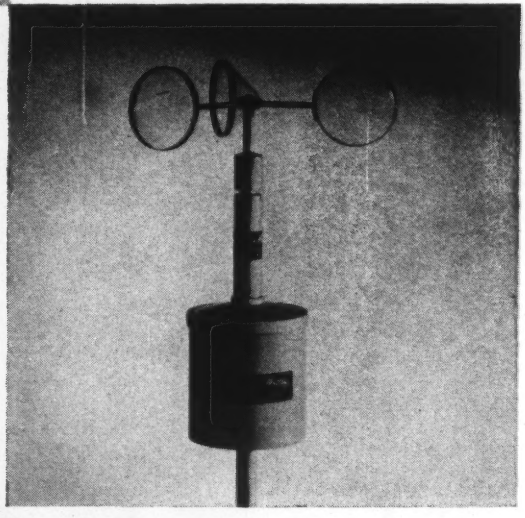

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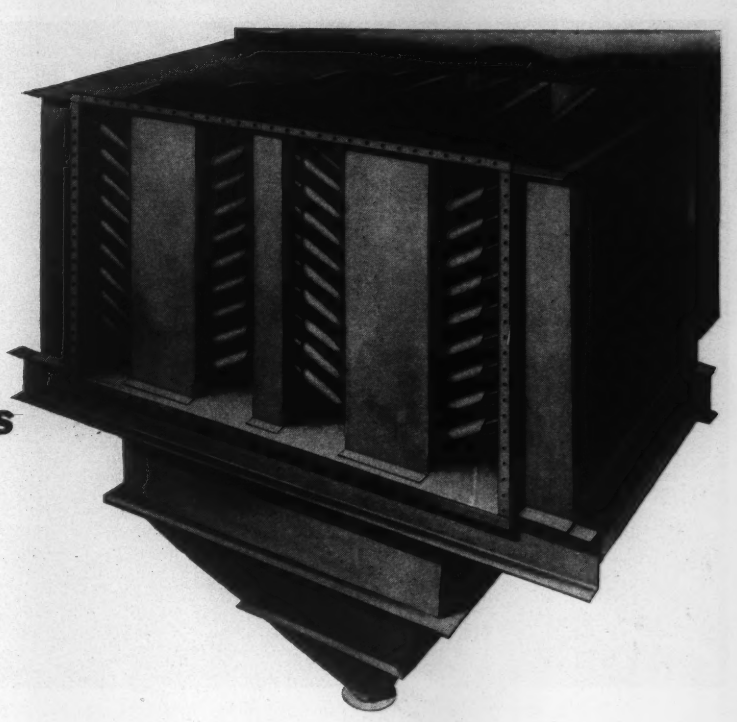

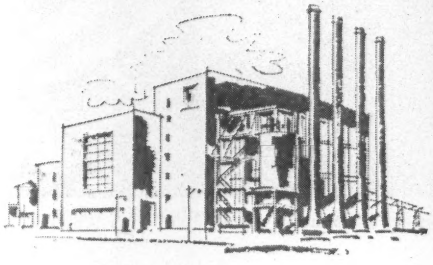

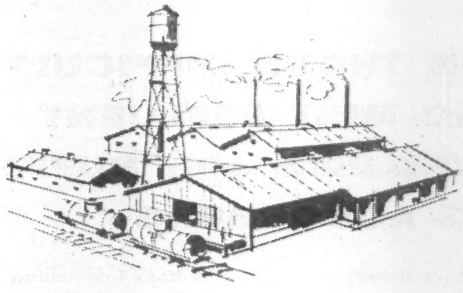

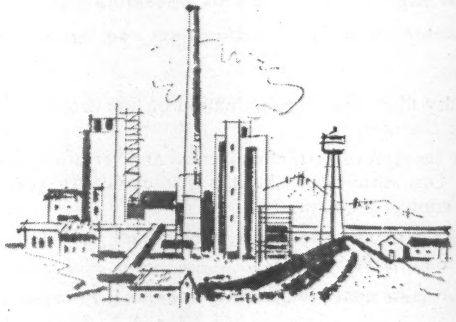

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JOURNAL OF THE AIR POLLUTION CONTROL ASSOCIATION

(Formerly "Air Repair")

A Bi-Monthly Journal Devoted to Air Purification

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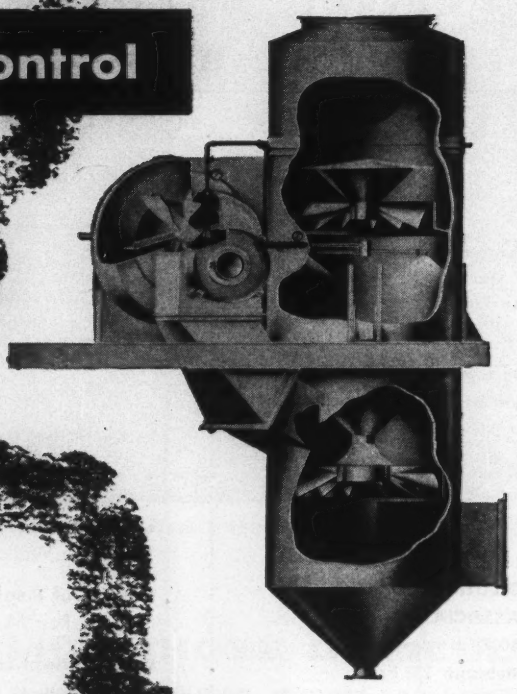
. . . in wet dust control



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LETTERS to the EDITOR

Editor:

This is to acknowledge with many thanks receipt of your letter enclosing my membership card to the Association.

Since air pollution and its control is one of the main subjects in the modern world, it is a great honor for me to cooperate with other members under the association and sincerely wish to elevate the value of the organization to the world.

I am looking forward with pleasure to receiving the materials forwarded.

Best regards,

HIROSHI NODA
Department Manager
Daido Steel Company, Ltd., Japan

Rebuttal of "Critique"

Editor:

Regarding the published "Critique" (Vol. IX, No. 3, Nov. 1959) of my recent article on "Effectiveness of Odor Counteractants for the Treatment of Stack Gases" (Vol. XI, No. 2, Aug. 1959) it is unfortunate that Mr. Turk's sponsors, Airkem, Inc., bound his thinking along so narrow a channel that it was neither possible for him to give consideration to all the data presented nor to attempt an adequate answer to the provocative questions raised in my discussion. I believe his commission: ". . . to extract from it (my article) any conclusions which might be important to validation of odor counteractant procedures" to be less than a proper basis for a critical review.

Mr. Turk's critique contains more misrepresentations than I can unscramble in a short letter but I would like to set the record straight on at least a few. First and foremost, I believe Mr. Turk is right when he argues that my report is less than a definitive study of the application of odor counteractants to stack effluents. But I believe he is wrong when he assumes that there is anyone who disagrees with him.

My call for "objective, factual data" has disturbed Mr. Turk unduly. A closer reading of the text would have revealed to him that I did not mean by this that only physical and chemical tests should be employed in the evaluation of odors (although I am sure he joins with me in looking forward to improved non-subjective tests) but rather that I deplore the use of non-objective, i.e. non-scientific, methods, such as unverified testimonials, to exploit these products. The meaning of "objective"

(*Continued on page 16*)

EDITORIAL

Is Your Fire Out?

With the publication of this number of the JOURNAL (you will not we are starting a new volume with this publication Volume 10, Number 1) a new era in APCA publications begins. Many arduous hours have been spent by your editoral staff and the two committees—Publications and Editorial Review—in assembling an all inclusive JOURNAL encompassing news in the field of air pollution control, technical articles and abstracts. Your ABSTRACTS this month are tucked in between the back cover and the last page. Next month, and in the alternate months when no JOURNAL is published, you will receive your ABSTRACTS in a separate mailing. We are extremely proud of the new format, and welcome comments and suggestions from our readers in the new "Letters to the Editor" column.

In this first editorial page we would like to stimulate the thinking of the membership along the lines of a membership campaign. You have all heard the old clichè "you get out of an organization exactly what you put into it" —it may be old but it still holds. When the late Robert T. Greibling first accepted the post of full-time executive secretary in 1951, APCA had a membership of 300! Now, going into the next decade, we have a membership of almost 2000. While this is an impressive growth, the number of sustaining and company memberships has remained stationary for the past several years. We have obtained many new corporate members. We have also suffered many losses. What impresses us most of all is that many corporate memberships join and then drop out as soon as they apparently are out of trouble. It appears, then, that APCA is used as a fire department. When an industry is in difficulty in its public relations program or with a control official, it is willing to participate and support the Association. As soon as the current fire is out a letter of resignation from the company or industry is received at headquarters.

Sustaining membership is the terminology applied to the $250 minimum dues set up for that particular classification—but it also means continued and sustained support. Air pollution control is not like a fire. It cannot be handled by hit or miss programming or support of APCA. True, some industries have been both heavy contributors financially and personnel wise as far as our service committees are concerned. However, others have adopted these "fire extinguisher" tactics.

The present dues of $10 for individuals and $50 for company memberships were effective in 1950, although the historical records indicate that the $10 figure has been in effect for some 40 years. The rate of inflation has been about 3.5 percent annually since 1950. To maintain equal purchasing power, dues should have been as shown in the following table.

Annual Dues Adjusted for Inflation

Year	Individual	Company	Year	Individual	Company
1950	$10.00	$50.00	1956	12.30	61.23
1951	10.35	51.75	1957	12.73	63.36
1952	10.71	53.60	1958	13.18	65.58
1953	11.09	55.23	1959	13.64	67.88
1954	11.48	57.16	1960	14.12	70.25
1955	11.88	59.16			

Increased service to the membership, as well as inflationary trends require additional dollars. We ask every member of APCA to consider this increased support. Remember, if APCA is to serve its members on something more than a fire alarm basis, it merits additional support from all classifications of membership.

Arnold Arch
Executive Secretary

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Join us at the 53rd Annual Meeting
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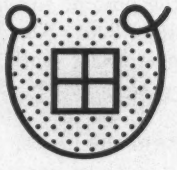

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   Title.....
   Address.....

7. Signed.....
   Title.....
   Date.....

Here is an opportunity to help your Association get its membership campaign off the ground. Use this application blank for new individual, company or sustaining members. If each APCA member brings in just one new member, we'll be well over the 4000 mark.

CONTAMINANT CONCENTRATIONS *in the Atmosphere of Los Angeles County**

WALTER J. HAMMING, Asst. Director of Research,
ROBERT D. MacPHEE, Chemist III, and **JAMES R. TAYLOR,** Head Research Asst.,
Los Angeles County Air Pollution Control District

The Los Angeles County Air Pollution Control District has operated a network of air monitoring stations for approximately three and one-half years. Automatic recording of various contaminants on a 24-hr basis is mandatory by virtue of the well-known Regulation VII, which was enacted as an aid to the prevention of any possible runaway pollution situation. In addition to its usefulness to warn of emergencies, the air monitoring network provides much valuable information on concentration levels and trends over the years.

Trends of Averages

In this paper we will describe average contaminant concentrations in the Los Angeles Basin, and show their trends over the past several years. In addition, simple graphical relationships of the contaminants with weather and smog manifestations have been derived. An IBM 650 computer and associated equipment were used to prepare our data. The scope of the report is in no way designed to detract from the importance of instantaneous maxima, comparisons of pollution in various areas of the County, frequency of the higher pollution levels, or a variety of other topics. All of these approaches are important in their own right, and are worthy of separate papers.

Only those contaminants that were collected with automatic devices on a 24-hr basis will be considered in detail although manual sampling records go back in some cases for 10 years. The manual sampling information, however, is spotty and not amenable to the present treatment. The automatic contaminant measuring devices include carbon monoxide (MSA non-dispersion infrared), nitrogen dioxide (Borman instrument-Saltzman reaction), oxidant (potassium iodide), and sulfur dioxide (Thomas Autometer). The operating principles involved in all of these instruments have been described elsewhere.[1] Particulate matter was also measured. Samples for particulates were collected by drawing air for an hour through filter-paper tape using a Chaney Autosampler.[2] The reflectance of the spot was obtained and results expressed in terms of K_m (blackness of filter spot).

The recorded data were read from the charts and key-punched onto cards. An OSCAR (Oscillograph Analyzer and Reader) was used for much of this work. Meteoroglogical information was gathered and summarized by the District's Meteorology Section from official U. S. Weather Bureau reports. Where wind speeds are described these are surface winds. Eye irritation data were obtained from a special tabulation maintained by Weather Bureau personnel (downtown Los Angeles office) for the District.

An average of 12 plant-damage stations were in operation in the Los Angeles Basin at all times from 1955–1959. The construction of the plant test boxes and system for evaluating damage using *Poa annua* and petunias has been described by Noble and Wright.[3] Several of the plant test stations were not tended on week ends or holidays, and the same plants served consecutively for several days. Where this occurred, the week end and holiday data were not used in this paper. For the most part only three stations were so operated (Nos. 1P, 6P and 58P). The procedure for plant testing involved daily exposure to smog of fresh, carefully-grown plants in test boxes, followed by an estimation of the percentage of total leaf damage. Only the "damage" or "no damage" portion of the data will be reported.

Locations of Measuring Stations

The location of the various contaminant test stations in the Los Angeles Basin, are shown in Figs. 1 and 2. These were selected on the advice of our meteorological staff to provide optimum coverage for the populace commensurate with the attainment of desirable experimental information. Modifying circumstances such as proximity to source emissions or availability of suitable facilities also entered into the selection of the sites. All sample inlets were as remote as possible from direct street fronting.

Station sites were changed with greater frequency than desired. In the early stages of such a program, this is bound to occur. This gives the Basin average data added importance.

Table I

Type I Primary Pollutants	Type II Secondary Pollutants
Have 2 diurnal peaks at approx. 0700 and 2000 PST.	Have 1 diurnal peak at approx. 1200 PST.
Have an annual peak in winter.	Have an annual peak in autumn.
Carbon Monoxide	Aldehydes
Hydrocarbons	Eye Irritant
Nitrogen Dioxide	Oxidant
Particulate (K_m)	Ozone
Sulfur Dioxide (?)	Plant Toxicant

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, Los Angeles, Calif., June 21–26, 1959.

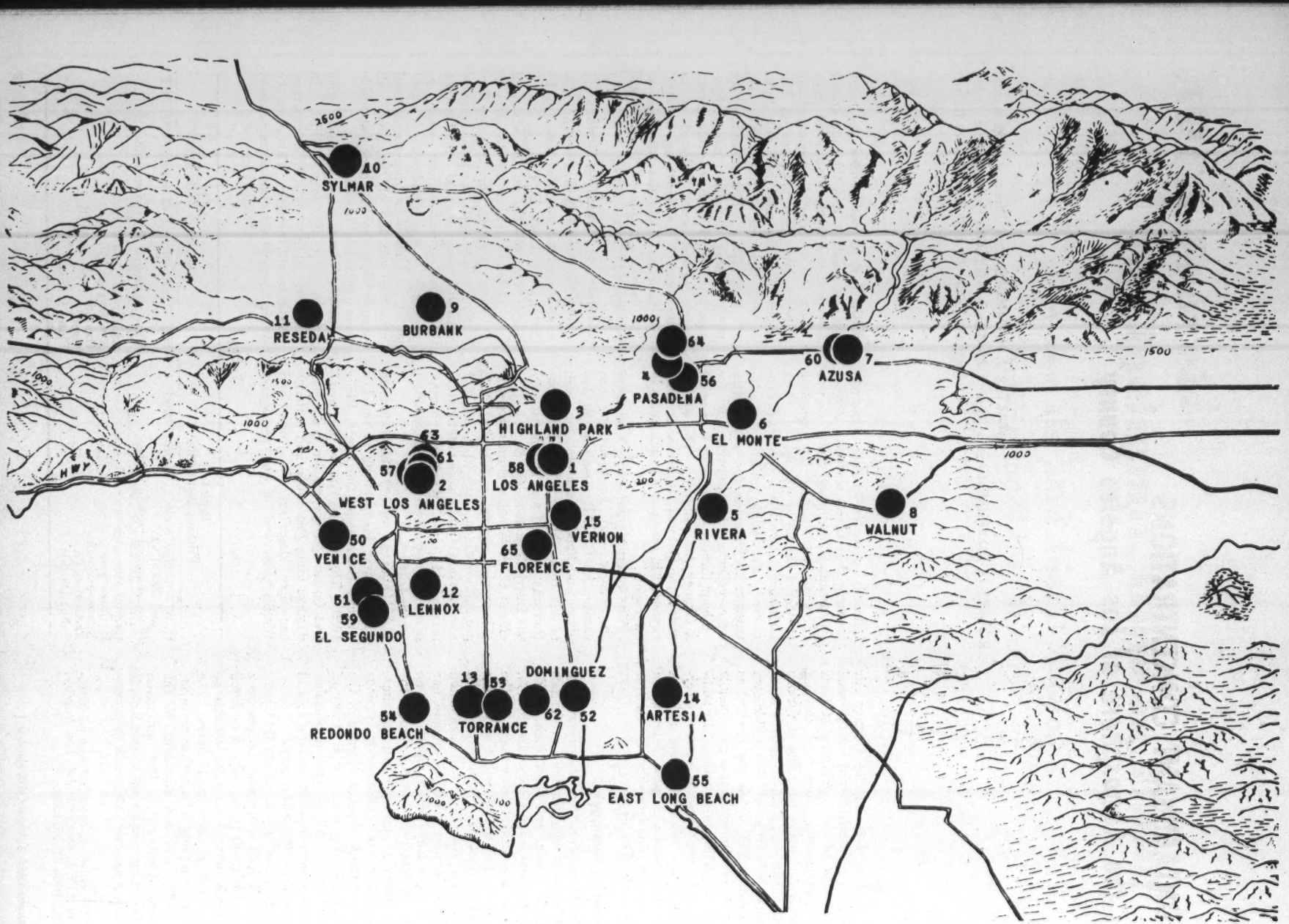


Fig. 1. Network of air contaminant stations maintained by the Los Angeles County Air Pollution Control District.

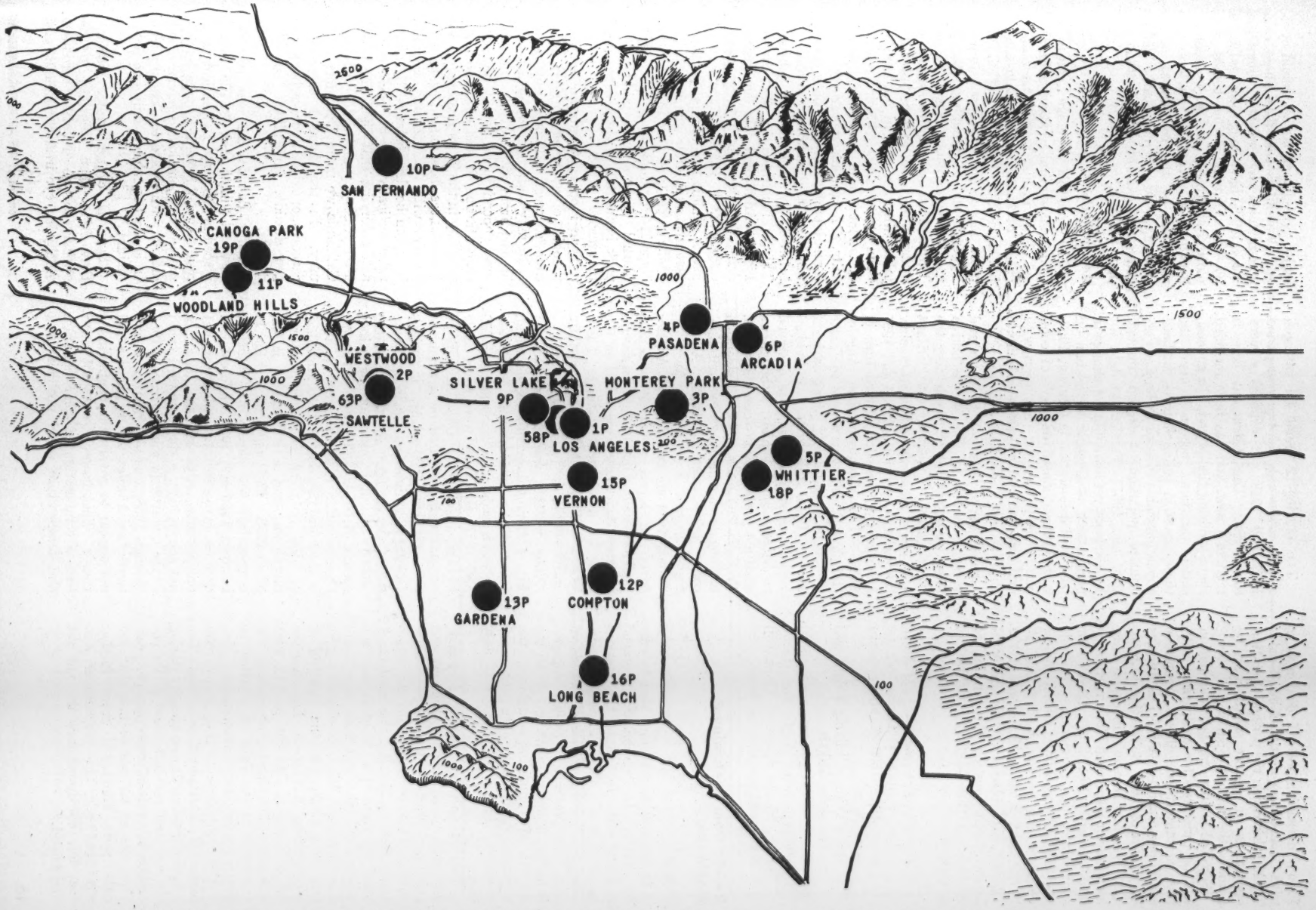


Fig. 2. Network of plant-test stations maintained by the Los Angeles County Air Pollution Control District. Stations located outside of the L. A. Basin have not been included in this paper.

In our discussion we will deal mainly with Basin-average countaminant data. Table I describing the periods of station operations in greater detail may be found at the end of the paper.

Selected meteorological information will be presented for comparison with the contaminants. These represent conditions observed at the Los Angeles City Office of the U. S. Weather Bureau. The Weather Bureau's inversion data have been incorporated into an arbitrary unit termed "Rule 57 Days" for convenience in correlation. In this way several important meteorological variables can be combined. Rule 57 is one of the legal regulations of the District. It places certain meteorological restrictions on the burning of rubbish. A Rule 57 Day is defined as one where:

1. The inversion base at 4:00 A.M., Pacific Standard Time, will be lower than 1500 ft above mean sea level.
2. The maximum mixing height will not be above 3500 ft.
3. The average surface wind speed between 6:00 A.M. and 12:00 noon, Pacific Standard Time, will not exceed five miles per hour.

Results from Contaminant Monitoring

Trends

In showing trends from year to year we prefer to emphasize averaged monthly data for all of the stations operated within the Los Angeles Basin. This minimizes vagaries of individual sites and presents a readily comprehensible figure for plotting. With the advent of computing machines, the averaging of masses of data such as are involved here is a relatively easy task.

The Basin-wide carbon monoxide level has risen steadily at about one ppm per year on the average since 1955. This is shown in the time-series plots in Fig. 3. The solid black lines represent the monthly average values and the dot-dash the trend lines (moving 12). A similar curve has been plotted to the right of it representing downtown Los Angeles for comparison. At the present time this slow continual rise cannot be explained in the light of weather or the trends for other contaminants.

The measurements from one carbon monoxide instrument at West Los Angeles (Station 2) rose steadily during the one and one-half years of its operation at a rate of seven ppm per year. This was so far out of line that the data were eliminated from further consideration. The mechanical reasons for this discrepancy are not yet understood.

The moving-12 trend for nitrogen dioxide covers only the two-year period 1957 and 1958. It exhibits a very slight rise. The instrument here is relatively new, and has been modified slightly during this period. In general, small variations occurred over the three years in sulfur dioxide, without any appreciable change in level. Particulate pollution decreased through 1956 and 1957. Particulate data for 1958 are not yet available. A change in particulates as a result of the ban on backyard incineration in October, 1957, was observed based on days of comparable meteorology.[4] For days with morning surface inversions a definite improvement was noted.

Switching to those contaminants and weather factors in Fig. 4, we find a more consistent set of trends over the three years. Oxidant, eye irritant and plant toxicants exhibited a slow downward trend during 1956 and 1957 followed by a smaller upward turn in 1958. The downtown Los Angeles station followed very nearly the same trends in oxidant and plant toxicant as the Basin-wide data. Individual trends for each station were observed to be reasonably similar, although we shall not present all of these data here. Probably the most popular conception of smog measurements are eye irritation, ozone alerts, and oxidant. All of these showed a minimum in 1957. Ozone alerts are called in Los Angeles based on levels of ozone over 0.5 ppm as measured manually.[5] In several instances two alerts were called on the same day at different stations. These would be represented as two separate entities in Fig. 4.

The weather factors presented in Fig. 4 exhibited overall trends which followed the contaminants. The 24-hr windspeeds were increasing in 1956 and 1957, and there were fewer Rule 57 Days. Rule 57 Days, it will be remembered, are based on a combination of low 4:00 A.M. inversions (<1500 ft), minimum rise in inversion during the forenoon (maximum mixing <3500 ft), and low morning windspeeds (6:00 A.M.–12 noon <5 mph). One exception to the complete picture is the slow rise during 1956 and 1957 of 6:00 A.M.–12 noon temperatures downtown, and a subsequent falling off in 1958. The long-trend increase in temperature was clearly not sufficient between 1956 and 1957 to forestall a decrease in eye irritation, plant toxicant or oxidant. Although the data are not shown here, a slight upward trend in the quantity of solar radiation, 1956 through 1958, was observed for downtown Los Angeles which likewise did not appear to govern the contaminant trends. This, however, does not mean that a combination of solar radiation and temperature could not act in a major capacity as far as annual cycles go. Visibilities less than three miles accompanied by relative humidities below 50% have long been tabulated by the District. The trends were plotted arbitrarily in Fig. 4 under the heading of Weather Factors. Irregardless of the correctness of the category, the trend clearly follows those for oxidant, eye irritant and plant toxicant.

Annual Cycles

The monthly average values for contaminants and weather data which are shown in Fig. 3 and 4 have annual cycles of high and low values which fall into two types. The following table repeats in condensed form the Types I and II groupings that were used in constructing Figs. 3 and 4. Three substances, hydrocarbons, aldehydes, and ozone, were included in the table, although we had not mentioned them previously. Their role was determined from manual sampling results. A certain regularity in the dirunal peaks has also been observed which serves to confirm the distinction between Types I and II substances. This is illustrated by the curves in Fig. 5. Additional data demonstrating daily variations have been presented elsewhere.[6–8] Briefly, Type I contaminants exhibit two diurnal peaks; one several hours after sunrise (so-called traffic peak) and one in the evening. Type II contaminants exhibit only one diurnal peak around midday. The peak hours shift slightly depending on the season.

Type I contaminants are commonly thought of as being emitted directly from sources. Although nitrogen dioxide may be formed in the atmosphere in part from nitric oxide, and, therefore, depend to an extent on oxidant concentration, it was found to line up perfectly in the Type I category. Type I substances show annual peaks in midwinter with a striking regularity. This can be demonstrated by laying a ruler vertically over the peaks in Fig. 3 and observing that they line up year after year. By midwinter in Southern California we mean December or January. In the Type I category are carbon monoxide, hydrocarbons, nitrogen dioxide, particulates, and sulfur dioxide.

Sulfur dioxide did not exhibit a clear-cut winter peak for 1957 and was placed in the Type I classification with reservation. Several groups have observed the anomalous behavior of sulfur dioxide with regard to dirunal peaking. In general it exhibits only one peak at midday.[7,8]

Type II contaminants, insofar as they have been identified to date, appear to be reaction products—aldehydes, eye irritant, oxidant, ozone,

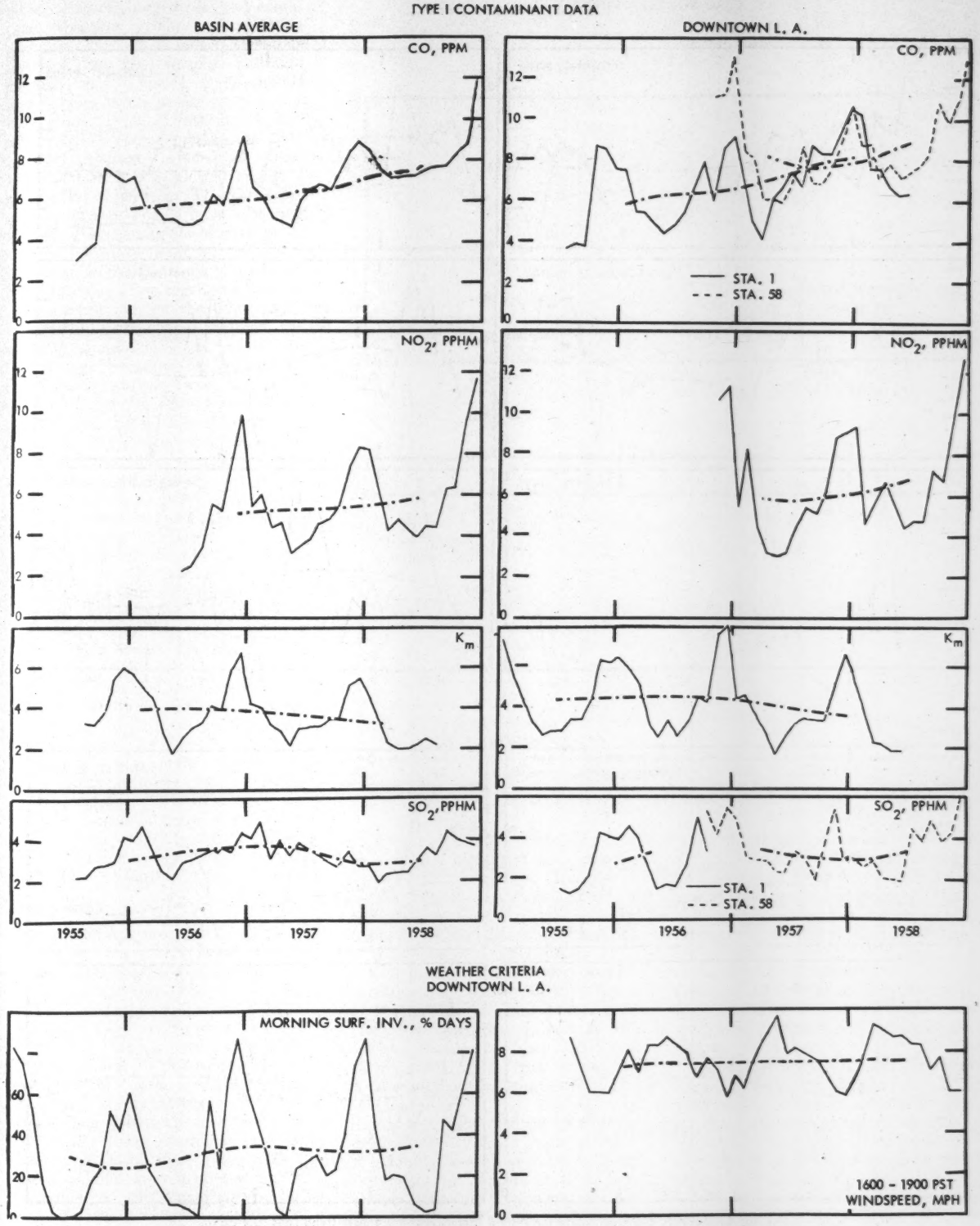


Fig. 3. Monthly average values for Type I factors showing annual trend lines (dot-dash).

and plant toxicant. The annual peaks for Type II substances, for the most part, appear in the autumn (August, September, or October).

Types I and II contaminants bear a relationship to winds and inversions. The major cause of inversions in mid-winter is radiation of heat from the ground to space during the late after-

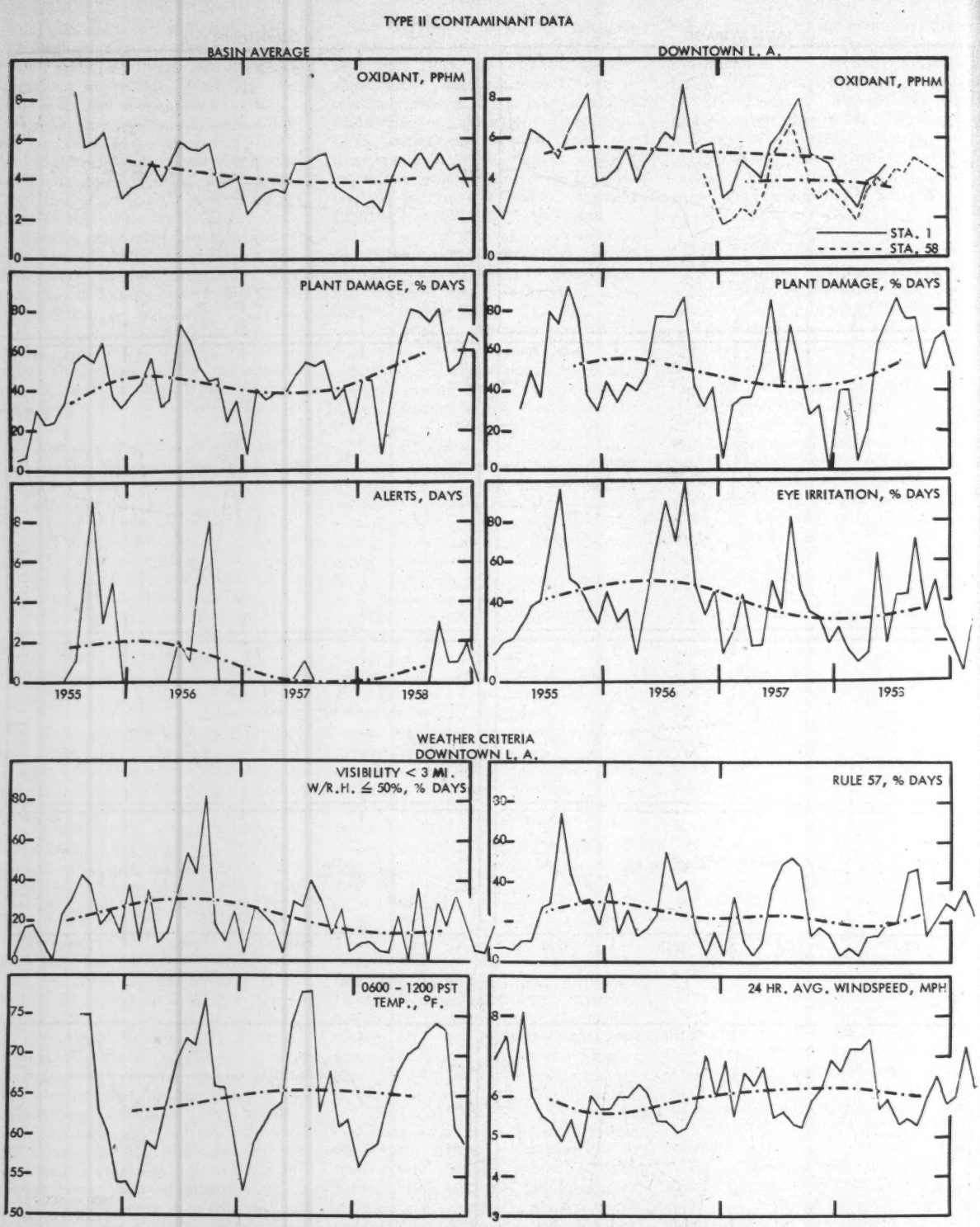


Fig. 4. Monthly average values for Type II factors showing annual trend lines (dot-dash).

noon and after dark. This, at times, disrupts the normal tendency of air (lapse rate) to become steadily cooler with elevation and produces an inversion. With warm air aloft the cooler air at the ground, the tendency for pollutants to rise and escape is thwarted. Resulting inversions are shallow, and the insolation the following day normally either breaks them or causes them to rise to a considerable height. The type of inversion which is being described here is termed a surface inversion. Such inversions are conducive to high Type I pollution during the night, with a second peak shortly after sunrise due to resumption of the days' activities and fresh pol-

lution being discharged. Type I conditions, therefore, yield two pollution peaks per day. It is indeed a curious facet of the Los Angeles pollution problem that Type I contaminants reach higher levels in the winter, at a time when Type II substances and smog troubles seldom plague the area. Monthly average windspeeds from 1600–1900 PST were plotted in Fig. 3 as a matter of interest. This particular segment of winds could have a bearing on Type I contaminants because of its cycle of midwinter minima. However, a more rigorous treatment is necessary before drawing a firm conclusion here.

In the autumn, on the other hand, the prevailing inversions are due to the dynamic circulation of air about the Pacific high pressure cell which not only moves air clockwise, but also downward due to subsidence at its eastern limb. The lowest levels are cooled by the ocean, and the upper levels warmed due to compression. These are called dynamic inversions. Moisture in the air near the coast, as witnessed by frequent clouding at night, radiates additional heat to space aggravating the intensity of the inversion. In the autumn, the resulting inversion is so strong that the following days' heating will cause it to rise slowly, and frequently, not dissipate. This favors the lingering of contaminants through the morning and allows time for the generation of Type II pollution. Type I contaminants begin to decrease as the inversion rises, but the Type II products continue to be generated for several hours, until removed by afternoon sea breezes. Type II contaminants are normally present in the winter only to a small extent, if at all, and when they are, the diurnal peaks occur several hours later than they do in the autumn.

Conclusions

The primary purpose of the paper was to describe long-term pollution trends as measured by the Los Angeles air monitoring network. This is the first time, to our knowledge, that such information has been reported. Except for work in England on a distinctly different type of air pollution problem, there are few data available which span any appreciable number of years. The District's monitoring is done with 24-hr recording devices. Its usefulness is justified primarily as a protection and warning measure. A by-product of this operation is the generation of data from which the levels and trends in pollution can be studied.

The findings may be summarized as follows:

1. During the three-year period, 1956–59, the general level of carbon monoxide has been rising. The rise in carbon monoxide of one ppm per year has not been reconciled with weather or other pollution factors. The rise in nitrogen dioxide was small and trends are available only from 1957. Sulfur dioxide varied slightly without changing its general level. Particulates (K_m) declined during 1956 and 1957. Particulate data have not yet been reduced for 1958. The decline during 1957 could have been due in part to the District's incinerator ban. A preliminary study on the basis of comparable weather factors appeared to justify this conclusion. The oxidant, eye irritant, and plant toxicant declined in 1956 and 1957 from a high in 1955, but exhibited a slight upturn in 1958. The shapes of the trend lines here resemble those for visibility, the frequency of Rule 57 Days, and the inverse of 24-hr average windspeed. Winds and inversions appear to the the determining factors for trends in eye irritant, oxidant and plant toxicant.

2. In examining the monthly average data used as the basis for the trend lines, it was observed that certain contaminant and weather factors could be grouped together. Monthly averages for primary, or Type I factors exhibited annual peaks in midwinter. These were carbon monoxide, hydrocarbons, nitrogen dioxide, particulates (K_m), sulfur dioxide (not perfect fit), frequency of morning surface inversions, and the inverse of 1600–1900 PST windspeeds. In addition, the Type I contaminants are known to yield bimodal diurnal variations.

Secondary, or Type II, entities showed annual peaks in the autumn, and single daily peaks. These included aldehydes, eye irritant, oxidant, plant toxicants, ozone alerts, restricted visibility, the frequency of Rule 57 Days, and the inverse of 24-hr average windspeeds.

Both the yearly and the diurnal cycles confirm the distinction between Type I and Type II pollutants.

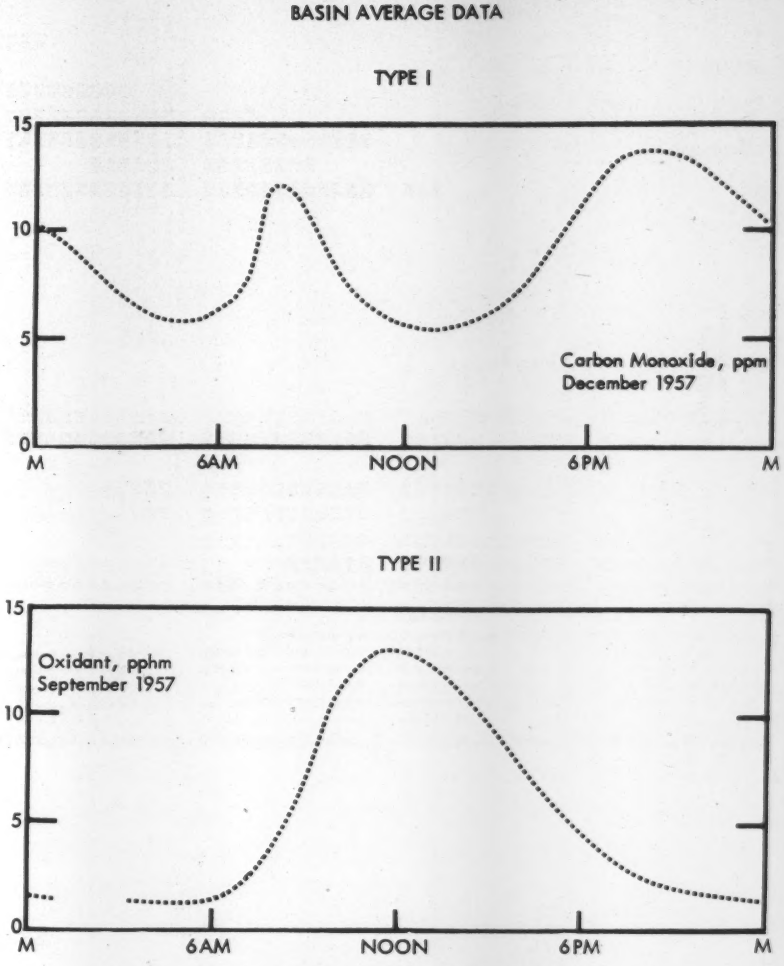


Fig. 5. Examples of Type I and II diurnal curves.

REFERENCES

1. J. C. Romanovsky, J. R. Taylor, R. D. MacPhee, and Janet R. Dickinson, "Air Monitoring of the Los Angeles

(*Continued on page 16*)

Table II—Log of Contaminant and Plant Station Operations

Carbon monoxide

Months	Station Numbers
1955	
J	1 5 15
A	1 5 15 56
S	1 5 15 56
O	1 2 3 5 6 9 15 56
N	1 2 3 5 6 7 9 11 15 56
D	1 2 3 5 6 7 9 11 13 15 56
1956	
J	1 2 3 4 5 6 7 9 11 13 15
F	1 2 3 4 5 6 7 9 11 13 15
M	1 2 3 4 5 6 7 9 11 13 15
A	1 2 3 4 5 6 7 9 11 13 15
M	1 2 3 4 5 6 7 9 11 13 15
J	1 2 3 4 5 6 7 9 11 13 15
J	1 2 3 4 5 6 7 9 11 13 15
A	1 2 3 4 5 6 7 9 11 13 15
S	1 2 3 4 5 6 7 9 11 13 15
O	1 2 3 4 5 6 7 9 13 15 58
N	1 2 4 5 6 7 9 13 15 58
D	1 2 4 5 6 7 9 13 14 15 58
1957	
J	1 2 4 5 6 7 9 13 14 15 58 60
F	1 2 4 5 6 9 13 14 15 58 60
M	1 2 4 5 6 9 13 14 15 58 60
A	1 2 4 5 6 9 13 14 15 58 60
M	1 2 4 5 6 9 13 14 15 58 60
J	1 2 4 5 6 9 13 14 15 58 59 60
J	1 2 4 5 9 13 15 58 59 60
A	1 2 4 5 9 13 15 58 59 60
S	1 2 4 5 9 13 15 58 59 60 61
O	1 4 5 9 13 15 58 59 60 61
N	1 4 5 9 13 15 58 59 60 61
D	1 4 5 13 15 58 59 60 61
1958	
J	1 4 5 9 13 15 58 59 60 61
F	1 4 5 9 13 15 58 59 60 61
M	1 4 5 9 13 15 58 59 60 61
A	1 4 5 9 13 15 58 59 60 61 62
M	1 4 5 9 15 58 59 60 61 62
J	1 4 5 9 15 58 59 61 62
J	4 5 9 15 58 60 61 62
A	4 5 9 15 58 60 61 62
S	4 5 9 15 58 60 61 62
O	5 9 15 58 60 61 62 64
N	5 9 15 58 60 61 62 64
D	5 9 15 58 60 61 62 64
Summary	
	1 2 3 4 5 6 7 9 11 13 14 15 56 58 59 60 61 62 64

Although a carbon monoxide instrument was operated for a year-and-half at Station 12, the data appeared to be highly irregular and were not included here.

Nitrogen Dioxide

Month	Station Numbers
1955	
J	
A	
S	
O	
N	
D	
1956	
J	
F	
M	
A	
M	Meas. started 6-20-56
J	6 13
J	1 2 3 4 6 9 10 12 13 15
A	1 2 3 4 6 9 10 11 12 13 15 58
S	1 2 3 4 5 6 7 9 10 11 12 13 15 58
O	1 2 3 4 5 6 7 9 10 11 12 13 15 58
N	2 3 4 5 6 7 9 10 11 12 13 15 58
D	2 3 4 5 6 7 9 10 11 12 13 15 58
1957	
J	2 3 4 5 6 7 9 10 11 12 13 15 58 60
F	2 3 4 5 6 9 10 11 12 13 15 58 60
M	2 3 4 5 6 9 10 11 12 13 15 58 60
A	2 3 4 5 6 9 10 11 12 13 15 58 60
M	2 3 4 5 6 9 10 11 12 13 15 58 59 60
J	2 4 5 6 9 10 11 12 13 15 58 59 60
J	2 4 5 9 12 13 15 58 59 60
A	2 4 5 9 12 13 15 58 59 60
S	2 4 5 12 13 15 58 59 60 61
O	4 5 9 12 13 15 58 59 60 61
N	4 5 9 12 13 15 58 59 60 61
D	4 5 9 12 13 15 58 59 60 61
1958	
J	4 5 9 12 13 15 58 59 60 61
F	4 5 9 12 13 15 58 59 60 61
M	4 5 9 12 13 15 58 59 60 61
A	4 5 9 12 13 15 58 59 60 61 62
M	4 5 9 15 58 59 60 61 62
J	4 5 9 15 58 59 60 61 62
J	4 9 15 58 60 61 62
A	4 9 15 58 60 61 62
S	4 9 15 58 60 61 62
O	9 15 58 60 61 62 64
N	9 15 58 60 61 62 64
D	9 15 58 60 61 62 64
Summary	
	1 2 3 4 5 6 7 9 10 11 12 13 15 58 59 60 61 62 64

Oxidant

Month	Station Numbers
1955	
J	1
F	1
M	1
A	1
M	1
J	1
J	1 5 15 50 53 56 57
A	1 5 15 50 53 56 57
S	1 5 15 50 53 56 57
O	1 3 5 9 11 12 15 50 53 56
N	1 2 3 5 6 7 9 11 12 15 53 56
D	1 2 3 5 6 7 9 11 12 13 15 56
1956	
J	1 2 3 4 5 6 7 9 11 12 13 15 56
F	1 2 3 4 5 6 7 9 11 12 13 15 56
M	1 2 3 4 5 6 7 9 11 12 13 15 56
A	1 2 3 4 5 7 9 11 12 13 15 56
M	1 2 3 4 5 6 7 9 11 12 13 15 56
J	1 2 3 4 5 6 7 9 11 12 13 15 56
J	1 2 3 4 5 6 7 9 11 12 13 15 56
A	1 2 3 4 5 6 7 9 10 11 12 13 16 56

Particulates (*Km*)

1955	
J	1
F	1
M	1
A	1
M	1
J	1
J	1
A	1 56
S	1 56
O	1 9 56
N	1 56
D	1 9 56
1956	
J	1 4 9
F	1 4 9
M	1 4
A	1 4 9
M	1 4 9
J	1 4 9
J	1 4 9
A	1 4 9

| | | |

Atmosphere with Automatic Instruments," paper presented at Air Pollution Control Association, Annual Meeting, Buffalo, N. Y. (May 21, 1956).
2. Los Angeles County Air Pollution Control District, Manual of Laboratory Methods, Test No. 3–54 (1958).
3. Wilfred M. Noble and Lloyd A. Wright, *Agron. J.*, **50**, 551–53 (1958).
4. L. A. APCD Analysis Paper No. 12, "A Preliminary Survey of Particulate Matter Levels as Pertaining to the Abolition of Single Chamber Incineration" (July 1, 1958).
5. Los Angeles County Air Pollution Control District, Manual of Laboratory Methods, Test No. 14-56 (1958).
6. G. P. Larson, J. R. Taylor, and W. J. Hamming, "Studies of Pollution Levels in Relation to Air Movement in the Los Angeles Atmosphere," Proc. 3rd National Air Pollution Symposium, Pasadena (April, 1955).
7. N. A. Renzetti, Editor, An Aerometric Survey of the Los Angeles Basin, Air Pollution Foundation Report No. 9 (July, 1955).
8. R. D. MacPhee, J. R. Taylor, Diurnal Variations in Contaminant Levels in Los Angeles Basin, L. A. APCD Analysis Paper 21, in preparation.

RESEARCH REPORT SHOWS PROGRESS

Substantial progress in establishing a petroleum industry program of oil-burner research was reported by an American Petroleum Institute consultant.

The report was made by David W. Locklin of the Battelle Memorial Institute, Columbus, Ohio, at a meeting of the Fuel Oil Committee of the API at its 39th Annual Meeting. Mr. Locklin is research consultant to the committee.

A study of research possibilities already has stimulated industry-wide interest in improving oil burners.

Mr. Locklin noted the desirability of co-ordinating independent research now being conducted by refiners and equipment manufacturers.

Research now is under way, Mr. Locklin said, in the atomization of fuels, fuel-air mixing, catalytic and surface combustion, combustion acoustics, new fuel-oil uses, new types of burners, modifications of existing burners and improvement in field installations to assist marketing and servicing organizations to retain their present customers.

Refiners, Mr. Locklin said, have expressed willingness to take on segments of an industry-wide research program in their own laboratories. Equipment manufacturers generally, he said, prefer that the petroleum industry develop data and principles which they, in turn, can use to develop new designs.

Within two or three months, Mr. Locklin said, a bibliography and review literature will be established to speed the communication of new ideas and data to all the industry.

Bay Area Has Special Library

A unique technical library on air pollution is maintained as a free public facility by the Bay Area Air Pollution Control District, San Francisco.

The library is unusual in several ways. It is the only major public facility of its kind in the region. It is one of only three or four large public air pollution libraries in the country, and its 7000 titles are within arm's length of one another.

This last fact is made possible by the use of the Uniterm Co-ordinate Indexing System which was set up for the District by Stanford Research Institute.

In addition to the modern microfilm system in the library, there are still a few busy "stack" units. These shelves permit storage of current periodicals and of volumes too thick to be microfilmed economically.

The library has proved useful to engineers and executives needing many facts on the design, installation, maintenance, and cost of air pollution control equipment. The District staff also uses it to good advantage to develop and maintain control programs.

Cincinnati Fights Ragweed Problem

The Air Pollution Control League of Greater Cincinnati is leading the fight to have ragweed destroyed during the spring and summer months, so that allergy victims may breathe easier, later.

"Get Ragweed Before It Gets You" is the theme of the League's program which enlists the aid of the public each spring and summer in the annual battle of "Operation Ragweed." Effective means of controlling the spread of such weeds are now available. To be effective the effort should be community-wide. An estimated 50,000 hay fever and asthma victims in Cincinnati alone are being helped by this community-wide program.

Through the efforts of the League and its Hay Fever and Weed Control Committee the City of Cincinnati has a Weed Control Ordinance which provides for notice or warning to be sent to property owners where weeds are growing.

The League's program includes a community-wide educational campaign with the help of the schools, fire departments, garden clubs, Camp Fire Girls, Boy Scouts and other civic organizations. Cooperation of public officials, industries, railroads and private property owners helps to reduce this menace to health, comfort and pocketbooks.

LETTERS TO THE EDITOR

(*Continued from page 5*)

should have been crystal clear to Mr. Turk since it was used in its proper sense by a spokesman for his sponsor in a passage which I quoted and by Mr. Turk himself in the August 1954 issue of *Air Repair* (p. 5) where he pointedly refers to "an objective approach" to odor-panel testing. (Apparently, in his more reflective moments he shares with me certain reservations with respect to odor evaluations by investigators with pre-formed notions.)

I am afraid Mr. Turk misinterprets once again when he objects to my observation concerning plant employees used as members of an odor-panel that "their reaction to foul odors would be less intense than that of the population in general" and offers in rebuttal: "It is equally conceivable that individuals who are familiar with an odor are especially alert and sensitive to it." A more careful reading of the text would have revealed to him that I took special pains to point out that these men were, in fact, especially sensitive to these odors (i.e. to their perception) by reason of their long familiarity with them but that their subjective response (i.e. their reaction to the foul odors) was tempered by this same familiarity. Therefore, and this is the whole point, if these workers found the stack objectionable, it could be anticipated that the general public would, also; although the reverse would not necessarily be true.

Mr. Turk's conclusions fail to make clear that I did not state or imply that the data in Table II of my article were relevant to an evaluation of the pleasantness of the odor. Table II does, however, supply useful information on whether the action of the chemical additive, if any, is odor-counteraction or odor-masking; a topic badly in need of further clarification.

If I interpret Mr. Turk's analysis and conclusions correctly, his major thesis is that this investigator did not recognize a good thing when he saw it; that, in fact, my experiments really proved that odor-counteraction was effective in controlling the stack odor problem. He arrives at this remarkable conclusion by carefully selecting only the "favorable" responses and subjecting these to a rigorous statistical analysis. Surely, his curious failure to examine and analyze almost two thirds of the relevant, though "unfavorable," data violates the very basis of statistical validity. What was discovered by his statistical analysis was clearly stated in my article as follows: "There is a measurable

(*Continued on page 93*)

EYE IRRITATION *from Air Pollution**

C. H. HINE, M. J. HOGAN, W. K. McEWEN, F. H. MEYERS, S. R. METTIER, and **H. K. BOYER,** Proctor Foundation and Department of Ophthalmology, and Department of Pharmacology and Experimental Therapeutics, University of California School of Medicine, San Francisco

The three most commonly recognized effects of general air pollution are eye irritation, damage to growing plants, and reduced visibility. While data have not been accumulated regarding the frequency with which eye irritation occurs, it is generally conceded that the incidence has been increasing in the Los Angeles area despite the many activities directed toward the control of air pollution. Since it is recognized that the health of the general public may be affected, those responsible for promoting research in the general area of health and air pollution have encouraged the study of airborne factors contributing to eye irritation, especially the obtaining of objective measurements of the degree of eye irritation.

Several excellent studies have been conducted. Among them are the project supported through the Air Pollution Foundation of Los Angeles, in conjunction with Stanford Research Institute and Midwest Research Institute; the projects collaborated in by the Air Pollution Control District of Los Angeles; and the project on nitro-olefins conducted at the Miami School of Medicine.

The study of eye irritation is complicated by the lack of satisfactory evidence of the degree and type of irritation. When the sensations are entirely subjective in nature and unaccompanied by objective findings, it is difficult to quantitate the degree of response. However, there has been excellent work on the effect of lacrimators and other substances of importance in chemical warfare on the anterior segment of the eye.

The purpose of this paper is to report the results of a study carried out at the University of California School of Medicine, jointly by the staff of the Proctor Foundation and Department of Ophthalmology, and the Department of Pharmacology and Experimental Therapeutics. A summary of the important findings of other groups has been included, since they contribute significantly to an understanding of the subject.

Experimental

The experiments which we conducted were of two different types. First, laboratory animals were exposed to graded concentrations of a number of pure chemical substances, selected for their known or supposed irritating effect on surface tissues, to mixtures of these, and to artificial smogs. The sensory responses of the animals were studied, as well as the histologic changes produced in the cornea and anterior chamber of the eye. Second, human volunteers were exposed to monitored concentrations of pure chemicals, mixtures, and simulated smogs, to determine their sensory responses. Their eyes were examined before and after exposure, to determine their physiologic status.

Animal Exposure

Healthy albino rabbits, with normal eyes, free from disease of the corneal surfaces, were exposed once for a period of four hours, or 25 to 34 times for a period of one hour.

They were exposed to the pure gases: sulfur dioxide, nitrogen dioxide, and ozone, and to the vapors of acrolein and a diepoxide. These compounds were also used in various mixtures, with and without the addition of a saline aerosol. Two types of synthetic smog were also used: (a) a highly olefinic (approximately 50 percent) hydrocarbon, or gasoline was reacted with ozone, with or without nitrogen dioxide, in the presence of ultraviolet light; and (b) the exhaust gases from a one-cylinder, four-cycle engine were similarly irradiated. Several concentrations were used, generally in a range exceeding that normally found in polluted community air, but low enough not to be lethal to a significant number of animals.

The corneas of the rabbits were examined with a slit lamp before and after exposure. The thickness of the cornea was measured by a pachymeter, and any evidence of discomfort during the period of exposure was noted. The regeneration rate of excoriated corneas was used throughout as an index of adverse effect, and certain biochemical measurements were carried out on tissue samples. The degree of chemosis and iritis was recorded on an arbitrary numerical scale.

The experimental design called for four rabbits to be used in each experiment, three exposed to the chosen irritant, and one control exposed to uncontaminated air. On day 0, a circular area of epithelium 10 mm in diameter was removed from the cornea of one eye of two experimental rabbits and the control, with the aid of a trephine. On day 1, 7-mm areas were similarly removed from the cornea of the other eye. A summary is presented in Fig. 1. The activity of four dehydrogenases in the excised tissue was studied: 6-phosphogluconate, malic, lactic, and glucose-6-phosphate. The activity was expressed in arbitrary units for wet and dry weight of tissue, and compared with that of the control sample taken at the same time. Details of the procedures have been reported elsewhere.[1]

In a few experiments, solutions of acrolein and a diepoxide were applied to the corneas directly.

A series of slides presented the exposure technics, method for trephining the cronea, appearance of the trephined cornea and normal rate of regrowth, appearance of the eyes after exposure, and changes in the cornea and anterior chamber produced by direct application of acrolein and by exposure to the

* Presented at the 52nd Annual Meeting of APCA, June 21–26, 1959, Statler Hotel, Los Angeles, Calif.

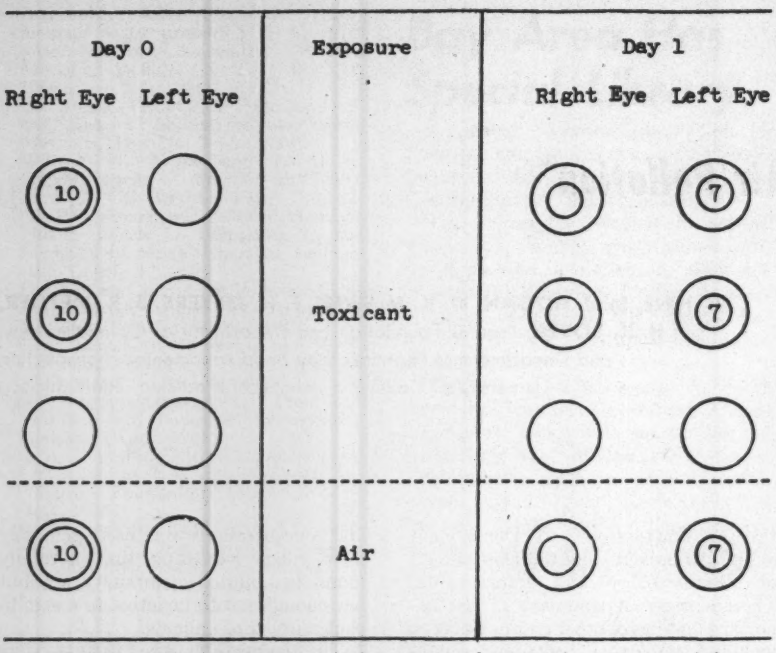


Fig. 1. Daily observations, pachymetry, and determination of regeneration rate are carried out.

diepoxide.

Results

The detailed data obtained from exposure of 28 rabbits in seven experiments to 2 to 2.4 ppm of ozone for four hours is summarized in Table I. No essential difference can be seen in the degree of chemosis or iritis, thickness of the cornea, or rate of regeneration, with the different exposures or treatments.

Table II, which summarizes the results of the acute exposure of rabbits to a number of compounds, shows that, with the exception of the epoxy compound, the irritants produced no objective evidence of effect on the anterior segment of the eye, even though the concentrations approached those causing severe respiratory effects in animals. The epoxy compound, representative of the diepoxides possibly present in polluted air, produced a series of changes by the conclusion of the exposure. Clouding of the cornea persisted for 72 hours after exposures were terminated, and gradually cleared over a week's time. Evidence of tissue repair was shown by vascularization, connective tissue overgrowth, and final resolution at the end of six weeks to a minimum area of scarring.

The effect of acrolein on the activity of the four dehydrogenases is summarized in Table III, and also the effect of nitrogen dioxide, sulfur dioxide, and ozone on malic dehydrogenase. Statistical analysis showed no significant differences between any of the exposed tissues and their controls (Table IV).

On chronic exposure, only sulfur dioxide, at 6 ppm, produced a positive effect. Here, thickening of the cornea was observed after 32 days. This effect was not observed at the higher concentrations of nitrogen dioxide, or even at near-lethal concentrations of ozone and acrolein.

Table I—Summary of Ophthalmologic Data on Acute Ozone Exposures

(Male rabbits, three months old, exposed for four hours at a temperature of 23 to 25° C. Air flow 480 LPM in 7 experiments, 1200 LPM in 4 experiments)

Corneal Area[a] mm.	Day moved	Number of Eyes	Concentration, ppm.	Range of Chemosis		Range of Iritis		Corneal Swelling, mm.
10	0	22	1.9–2.8	+	++	0	++	0.2–0.3
		11	0	+	++	+	++	0.2–0.3
7	1	22	1.9–2.8	0	+	0	+	0.1–0.2
		11	0	0	±	0	+	0.1–0.3
0		22	1.9–2.8	0	0	0	0	0

[a] Circular area of corneal epithelium removed, as diagrammed in Fig. 1. Regeneration rate about 3 days, occasionally 4 days.

Human Exposure

The subjects were chosen principally from among medical students and staff of the University of California School of Medicine. Groups of five or 10 were exposed within the exposure chamber in the Department of Pharmacology and Experimental Therapeutics, designed and used for experiments in sensory threshold determination.

The exposures were dynamic, with air changes eight to 16 times per hour. The lighting was controlled and uniform. The degrees of sensory response elicited was recorded by the subjects at one-minute intervals for six minutes. Eye irritation, nose irritation, pulmonary discomfort, olfactory recognition, and CNS (headache, vertigo, nausea, or other) effects were recorded according to degree: absent, slight, moderate, severe, or extreme. The corneas were inspected before and after exposure by the attending ophthalmologist. Delayed effects were reported and were weighted.

Results

The volunteers reported the greatest degree of irritation from sulfur dixoide at a concentration of 9.1 ppm (Table V). This gave a rating of 2.5, midway between "moderate" and "severe." As the response was recorded at one-minute intervals, it was possible to determine whether the irritant effect altered during the exposure period. In general, it appeared to decrease with time; the only notable exception was the response to acrolein.

Three exposures to uncontaminated air, using 10 subjects each, gave average sensory responses of 0, 0, and 0.1; for purposes of comparison, 0.1 was used

Table II—Data on Objective Tests for Evidence of Exposure of Rabbits to Irritants

Compound	Level, ppm.	Results
Acrolein	2, 5, 8	—
Nitrogen dioxide	20	—
Ozone	2	—
Sulfur dioxide	10	—
Sulfur dioxide + aerosol	10	—
Nitrogen dioxide + ozone + sulfur dioxide	5 4 2	—
Nitrogen dioxide + (irradiated) ozone + (irradiated) sulfur dioxide (irradiated)	8 8 2	—
Nitrogen dioxide + (irradiated) gasoline (irradiated)	2 10	—
Nitrogen dioxide + ozone + gasoline	2 2 10	—
Gasoline engine exhaust, irradiated	?	—
Diepoxide	3, 12	+

Table III—Summary of Effects of Single Four-hour Exposures of Dehydrogenases

(Dehydrogenase activity expressed in arbitrary units calculated on a dry-weight basis)

Compound	No. of Rabbits	Dehydrogenase Activity: Malic	6-Phospho-gluconate	Glucose-6-phosphate	Lactic
Acrolein[a]					
Exposed	4	1.8	0.5	1.6	2.5
Control	6	2.5	0.7	1.3	3.2
Sulfur dioxide					
Exposed	14		1.7		
Control	21		1.6		
Exposed	39	3.8			
Control	52	3.8			
Ozone					
Exposed	4	2.2			
Control	8	2.7			
Nitrogen dioxide					
Exposed	4	2.4			
Control	3	2.3			

[a] The figures for acrolein controls include corneal epithelium both from animals prior to exposure, and from animals exposed to control conditions.

as the "no effect" score. In every exposure, there was at least one subject whose response was not greater than "slight," and in most exposures there was at least one "moderate" response. This indicates the range of variation in response among the 20 subjects in the exposed group.

Comparison of exposures at the same level with and without aerosol showed no significant potentiation by the aerosol.

Exposure to 10 ppm gasoline with nitrogen dioxide and ozone produced a response of 1.8, approaching "moderate" irritation. However, in a similar experiment where the concentration of gasoline was only 1.5 ppm and the ratio of ozone and nitrogen dioxide proportionately reduced, a response of 0.2 was recorded, which is just above the background blank.

From the data obtained with this group of subjects, we did not find convincing evidence that more than very minimum irritation results from conditions which have been considered by others to simulate smog conditions.

Discussion

Mann and his co-workers at Johns Hopkins[2] have studied extensively the reaction of the anterior segment of the eye to the chemical injury produced by certain chemical warfare agents. They found that lacrimators combined irreversibly with sulfhydryl groups in proteins and could, in rather low dilutions, inactivate enzymes which depend on the presence of free SH-groups for their activity. These substances were all particularly toxic to pyruvic dehydrogenase and hexokinase. In our study, no significant decrease in enzyme activity could be demonstrated, and we can only conclude that the chemical reactions of the lacrimators are of a different order of activity, or that the concentrations used in Mann's studies considerably exceeded those obtained in our *in-vivo* exposures.

Mann's group also demonstrated that the chemical warfare agents could produce distinctive patterns of pathological response, which depended on the interaction of cellular tissue elements. The tissue reactions they observed consisted principally of edema, vascularization, hemorrhage, fibrosis, and cellular infiltration. The early stages of injury were characterized by edema of the stroma, occlusion of the small capillaries, and necrosis of epithelium. Microscopically, the earliest change noted in the corneal epithelium was fragmentation of the nuclei in the basal layers of cells, followed by detachment of epithelial cells from the underlying stroma. Stroma damage was manifest by edema of the posterior portion, occurring as early as one hour after injury. Damage to the iris was relatively mild. Repair commenced with migration of uninjured epithelial cells from adjacent areas of the conjunctiva. New groups of capillaries re-established the circulation, and pearly white areas indicated the chronic areas which had remained acellular. Very much dilated blood vessels were observed in some eyes.

This identical pattern was seen in our experiment with the diepoxide at 10 ppm. It was not seen with any of the other irritant gases tested. We must conclude from our experiment, therefore, that the concentrations of air pollutants which are likely to be met with in polluted community air are not sufficient to cause significant biochemical deviation, and that the mechanism for eye irritation is not demonstrable from the evidence now available.

Two essentially different types of experiment with human subjects have been used in evaluation of the eye-irritating effect of air pollutants. One of these requires a selected panel, observed under experimental conditions, while the other depends on panels at large in the community and not respondent to direct experimental observation.

Table IV—Summary of Effects of Repeated Exposure of Rabbits

(Three rabbits in each group were exposed four hours daily, and one rabbit in each group was exposed to uncontaminated air as a control. The humidity varied between 35 and 52%)

Compound	Average Concentration, ppm.	Number of Days	Effect on Eyes
Acrolein	0.6	30	—
Ozone	2.0	25	—
Sulfur dioxide	6.0	32	—[a]
Nitrogen dioxide	18	34	—

[a] Corneal thickness ± 0.04 mm.

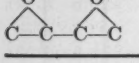
Select Panels

With the select group, the measurement of subjective effect can be recorded in terms of the intensity of response to the stimulus, as was the procedure of our group. It can also be expressed in terms of the time required to just recognize the presence of an irritant, a method used very successfully by Deichmann and his group.[3] Their summary of response-time following exposure to 2-nitro-2-butene (one of the more active nitro-olefinic combinations) is reported in Table VI. At concentrations below 0.2 ppm, the time required for response approached the total time of exposure.

In another type of select panel scoring, a series of gradations of response are recorded in terms of intensity of stimulus, and an arbitrary value is assigned for each level. The greatest objection to this method is that there is no justification for assuming a mathematical relationship between a slight and a severe exposure. Also, the response of one exceptionally susceptible (or resistant) subject weights the score toward a spuriously high (or low) value. It is apparent, therefore, that it is extremely difficult to determine mathematically a reasonable irritation value based on subjective responses. A similar difficulty is experienced during the clinical trials of analgesic compounds, as is well recognized by experimentalists.

A number of excellent emperiments have been carried out by the Stanford Research Institute and the Midwest Research Institute. It is not feasible to review these studies in detail, and for the purpose of this presentation it will suffice to summarize the more important points reported to date. A series of excellent diagrams and tables have appeared in reports of the Air Pollution Foundation, and the reader is referred to them for more detailed information.[4–6] The following statement summarizes the findings, with regard to the effects of air artificially polluted by irradiated automobile exhaust on the eye:

Table V—Summary of Results of Sensory Threshold Studies

Compound	Concentration, ppm.	Score
Ozone	3.7	1.2
	2.0	0.9
	1.6	
Ozone + aerosol	2.0	0.9
Sulfur dioxide	9.1	2.5
	5.4	1.0
Sulfur dioxide + aerosol	5.4	1.4
Nitrogen dioxide	0.7	0.4
Nitrogen dioxide + aerosol	0.6	0.3
Nitrogen dioxide + gasoline	2	0.8
	10	
Nitrogen dioxide + gasoline	10	0.1
	10	
Nitrogen dioxide + (irradiated) gasoline	2	1.6
(irradiated)	10	1.6
Nitrogen dioxide + ozone + gasoline	3	
	3	1.8
	10	
Nitrogen dioxide + ozone + gasoline	0.25	
	0.5	0.2
	1.5	
Ozone + (1 or 4 mercury lights)	0.2	1.0
Formaldehyde	3	0.7
	6	1.3
Formaldehyde + aerosol	6	1.7
	1	0.1
	4	0.2

The intensity of eye irritation produced by polluted air is dependent on the concentration of hydrocarbons and nitric oxide, and on the hydrocarbon/nitric-oxide ratio. Not all hydrocarbons are of equal importance in the generation of aerosols or the production of eye irritants; the C_4 and C_5 olefins appear to be the most important in this respect. It appears that olefins cause much more eye irritation than paraffins, and that the branch-chain olefins are more irritating than straight-chain. Increasing the chain length increases eye irritation up to a maximum of five carbons, and olefins with internal double bonds appear to be more irritating than those with terminal double bonds. As regards ring compounds, cyclohexene is more irritating than benzene, cyclohexane, or the straight chain in hexane.

The intensity of eye irritation produced by irradiation of automobile exhaust varies in proportion to the length of radiation time, up to four hours. Eye irritants produced by this method have approximately a 12-hour half-life, and are not intimately associated with the concentrations of ozone, aerosol, peroxyacetyl nitrite, or aldehyde. They are relatively unaffected by changes in relative humidity between 30 and 80 per cent, or by changes in temperature between 25 and 45°C. The production of eye irritants depends in part on light intensity, at levels below two-thirds that of sunlight. However, an increase to twice the intensity of sunlight produces little effect on the intensity of eye irritation.

The concentration of hydrocarbons and nitric oxide is determined by car variables, whereas the relative amounts of individual hydrocarbons are determined by the fuel consumed. The production of eye irritation is as much affected by the one as by the other.

The relation between eye irritation and particle size is still not clearly resolved. Goetz's experiments would seem to indicate that a relationship exists whereby removal of particles down to 0.2 micron reduces eye irritation.[8] Moreover, Dautrebaude[8] has reported that the addition of carbon black or sodium chloride aerosols to atmospheres which contain SO_2 and SO_3 in concentrations so low that they do not produce irritation in ten minutes of exposure results in definite irritation of eyes, nose, and throat.

Panels at Large

The study carried out by Merrifield in Los Angeles[9] used panels at large in the community to determine human responses. He found that at certain times of the year there seems to be good correlation between several of the commonly monitored contaminants and eye irritation. However, only oxidant levels showed a significant partial correlation when other contaminants and meteorological factors were held constant. Later work suggested that eye irritation did not appear unless there was a substantial amount of ether-soluble aerosol present in particulate form.[10] Chambers[11] has suggested that particular matter collected in a glass filter and then extracted yielded a fraction with a halfway potential of 1.03 volts, measured polarographically, and that this seemed to parallel eye irritation.

Summary

Eye irritation remains one of the major demonstrable ill effects of community air pollution. Experimental work reported in this paper does not demonstrate any objective evidence of histologic or biochemical change following exposure to relatively high concentrations of single or combined pollutants or artificial smogs. Measurements using human panels, by a number of groups, have contributed to a further understanding of the factors which lead to the formation of the eye-irritating components of polluted air, even though these have not as yet been identified.

Table VI—Summary of Response Time following Exposure to 2-Nitro-2-Butene (University of Miami)

Concentration (ppm)	No. Exposed	Response Time (seconds)
2.2	10	21.0 (12.9–33.9)
1.7	10	37.4 (20.4–70.8)
1.1	5	30.7 (25.2–38.4)
0.6	5	68.3 (40.5–87.5)
0.2	5	133.0(104–190

REFERENCES

1. S. R. Mettier, H. K. Boyer, C. H. Hine, and W. K. McEwen, "A study of air pollutants at low levels: Acrolein, ozone, sulfur dioxide, and nitrogen dioxide. I. The ophthalmological and biochemical effects on the anterior segment of the eye." *In press* Arch. Indust. Health.
2. I. Mann, A. Pine, and B. D. Pullinger, "An experimental and clinical study of the reaction of the anterior segment of the eye to chemical injury, with special reference to chemical warfare agents," *Brit. J. Ophth. Monograph Suppl.* **13** (1948).
3. W. B. Deichmann, M. L. Keplinger, G. E. Lanier, "Acute effects of nitro-olefins upon experimental animals," *Arch. Indust. Health* **18**, 312 (1958).
4. P. A. Leighton and W. A. Perkins, Solar radiation, absorption rates, and photochemical primary processes in urban air. Air Pollution Foundation Report No. 14, Los Angeles (March, 1956).
5. F. V. Morriss and C. Bolze, Reactions of auto exhaust in sunlight. Air Pollution Foundation Report No. 19, Los Angeles (March, 1957).
6. W. L. Faith, N. A. Renzetti, and L. H. Rogers, Automobile exhaust and smog formation. Air Pollution Foundation Report No. 21, Los Angeles (October, 1957).
7. A. Goetz, Reported by Chambers, Reference 11.
8. L. Dautrebaude, R. Capps, and E. Weaver, "Studies on aerosols. IX. Enhancement of irritating effects of various substances on the eye, nose and throat by particulate matter and liquid aerosols in connection with pollution of the atmosphere," *Arch. Int. Pharmacodyn.* **82**, 505 (1950).
9. Merrifield, reported by Chambers, Reference 11.
10. Orcutt, ibidem.
11. L. Chambers, "A synopsis of eye irritation in Los Angeles during the past 12 months." Proc. 2d Air Pollution Research Planning Seminar, Cincinnati, p. 21 (Feb. 3–7, 1958).

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Evaluation of Methods for CONTROLLING VEHICULAR EXHAUST*

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Introduction

For several years the role of automobile exhaust gases in the formation of smog has been the subject on intensive study. The exhaust gases of gasoline-powered motor vehicles contain nitrogen, oxygen, carbon dioxide, and water vapor. In addition to these components which constitute approximately 95–98 per cent of the exhaust gases, there are lesser quantities of carbon monoxide, hydrogen, hydrocarbons, partially oxidized hydrocarbons, oxides of nitrogen, and oxides of sulfur. Particulate matter, such as carbon particles, oil droplets, or other non-volatile materials, is also present.

It has been shown that hydrocarbons and hydrocarbon derivatives and oxides of nitrogen react photochemically in the atmosphere, giving rise to many of the manifestations of smog, such as eye irritation, reduced visibility, and damage to certain sensitive crops.[1, 2]

Although it is difficult to assign exact values to the many factors involved, overall estimates of the contaminant emissions for Los Angeles County have been computed on the basis of available data as shown in Table I.[3]

Motor vehicle exhaust gases account for approximately 65 per cent of the hydrocarbons and 60 per cent of the oxides of nitrogen emitted. It is obvious from these figures that automobile exhaust is one of the most important contributors to smog in this area. It follows that substantial reduction of contaminants from automobile exhaust gases is essential to achieve success in controlling smog. The California State Legislature, recognizing the important role of the automobile in smog, has passed legislation requiring standards for emissions to be established by the California Public Health Department.[4]

Characteristics of Gasoline-Powered Motor Vehicles

The gasoline-powered, spark-ignited, four-cycle internal combustion engine is today the motive power for essentially all the passenger cars and a majority of the motor trucks in operation.

In the four-cycle engine, the following sequence occurs through two revolutions of the crankshaft or four strokes of the piston:

1 Intake stroke—a mixture of fuel and air is drawn into the cylinder.
2 Compression stroke—the air-fuel mixture is compressed
3 Power stroke—the mixture is fired
4 Exhaust stroke—the burned gases are forced out of the cylinder

The power output and speed of the engine under varying load conditions are governed by the weight of air and fuel admitted. The carburetor meters out fuel in proportion to the amount of air drawn into the engine. During cruising the air-fuel ratio is around 15:1. Under accelerating conditions a considerably richer mixture is provided, having an air-fuel ratio around 12.5:1. With stoichiometric mixtures, hydrocarbon emissions are low, but oxides of nitrogen are at a maximum. Under power mixture ratios near 12.5:1, higher hydrocarbon emissions result, but the concentrations of oxides of nitrogen are lower.

The combustion chamber in each cylinder of the internal combustion engine is surrounded by cooling water. The gaseous fuel mixture in contact with or very close to the combustion chamber walls is cooled through the rapid conduction of heat to the metal. This cooling tends to prevent complete combustion, resulting in organic contaminants in the exhaust gases.[5] In practically all of the modern gasoline engines the combustion chamber provides a quench area at the top of the piston stroke for minimizing detonation. This quench area provides a high surface to volume ratio. In this portion of the combustion chamber the effect of the cooling surfaces in retarding complete combustion is intensified.

The greatest concentrations of unburned hydrocarbons are produced during the deceleration cycle. This phenomenon has little to do with the condition, make, model or type of engine involved but is inherent in all gasoline-powered internal combustion engines. Figure 1 shows the exhaust valve open (A) with the piston at bottom dead center and starting its upward travel to scavenge the exhaust material from the cylinder.

In (B), the piston has reached top dead center, the exhaust valve has closed, and the intake valve has opened. During deceleration a high vacuum exists in the intake manifold since the pistons are trying to draw in air against the restriction of a closed throttle. The exhaust gas material remaining in the cylinder, when the intake valve is opened, is drawn back into the intake manifold due to the high vacuum existing in this area.

As the piston starts down on the suction stroke, as shown in (C), the exhaust gas material, just previously drawn into the intake manifold, is now pulled back into the cylinder along with a small amount of fresh gasoline and air charge. The fresh charge drawn into the cylinder is so diluted with exhaust gas that it fails to burn and hence passes out the exhaust as unburned hydrocarbons.

The exhaust gas volume and air-fuel ratio are essentially the same during deceleration and idling. This is because

Table I—Comparison of Automotive and Total Emissions for Los Angeles County

	Emissions, T/Day				
	Hydrocarbons	Other Organics	Oxides of Nitrogen	Carbon Monoxide	Sulfur Dioxide
Total, all sources	1400	200	700	5400	500
Automotive exhaust	900	30	430	4200	50
Automotive carburetor and tank evaporation	25	0	0	0	0

* Presented at the 52nd Annual Meeting, APCA, Statler Hotel, Los Angeles, Calif., June 21–26, 1959.

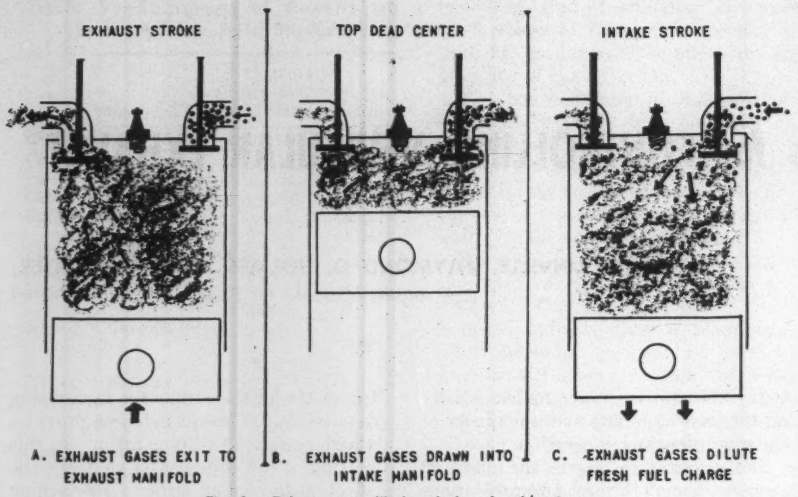
EXHAUST STROKE
TOP DEAD CENTER
INTAKE STROKE
A. EXHAUST GASES EXIT TO EXHAUST MANIFOLD
B. EXHAUST GASES DRAWN INTO INTAKE MANIFOLD
C. EXHAUST GASES DILUTE FRESH FUEL CHARGE

Fig. 1. Exhaust gas dilution during deceleration.

critical velocities exist both in the air flow through the closed carburetor and the fuel mixture flow through the idle circuit.

Under idling conditions, the manifold vacuum is lower and the exhaust dilution effect is less than under deceleration. The dilution effect is still sufficient, however, to make it necessary to provide an enriched air-fuel mixture to maintain satisfactory idling performance. This enriched condition results in a high concentration of unburned fuel during the idling cycle.

Losses of hydrocarbons may occur through carburetor vents to the atmosphere or through evaporation from the gasoline tank, or both. These emissions are variable, depending largely upon temperature and driving conditions, and may reach a rate for the Los Angeles area as high as 50 t/h at 100°F.[6] The control methods discussed in this paper are limited to control of exhaust emissions and do not cover evaporation losses.

Table II—Typical Automobile Exhaust Gas Measurements

Quantity Measured	Driving Cycle: Idling	Acceleration	Cruising	Deceleration
Hydrocarbons (as hexane), ppm	800	540	485	5000
Hydrocarbons, range (as hexane), ppm	300–1000	300–800	250–550	3000–12000
Acetylene, ppm	710	170	178	1096
Aldehydes, ppm	15	27	34	199
Nitrogen oxides (as nitrogen dioxide), ppm	23	1543	1270	6
Nitrogen oxides, range (as nitrogen dioxide), ppm	10–50	1000–4000	1000–3000	5–50
Carbon monoxide, %	4.9	1.8	1.7	3.4
Carbon dioxide, %	10.2	12.1	12.4	6.0
Oxygen, %	1.8	1.5	1.7	8.1
Exhaust gas volume, scfm	8	60	35	8
Exhaust gas volume, range, scfm	5–25	40–200	25–60	5–25
Exhaust gas temperature, range, °F (at muffler inlet)	300–600	900–1300	800–1100	400–800
Rate of fuel consumption by cycles, gal/hr	0.495	3.39	1.94	.495
Unburned fuel (as hexane), wt % of fuel supplied	2.88	2.12	1.95	18.0

Table III—Percent of Total Hydrocarbon Contribution by Cycles

Driving cycle	Driving Time: Total, %	Driving Time: Time Ratio	Exhaust Volume: Scfm	Vol. Ratio	Ratio × Vol. Ratio	H-C Conc., ppm	Time Ratio × Vol. Ratio × H-C Conc.	H-C Contribution, %
Idling	19	1.0	8	1.0	1.0	800	800	5
Accel.	19	1.0	60	7.5	7.5	540	4050	26
Cruising	37	2.0	35	4.4	8.8	485	4270	27
Decel.	25	1.3	8	1.0	1.3	5000	6500	42
							15620	100

Driving Variables

Because contaminant concentrations vary considerably under various operating conditions, it is necessary to define these conditions and to determine the relative contribution of each to the overall operation. The four cycles of engine operation have been defined by the District as follows:

1 Idling—Engine idling normally with closed throttle (transmission in neutral)
2 Acceleration—Throttle open and manifold vacuum below 12 in. of mercury
3 Cruising—Throttle open and manifold vacuum above 12 in. of mercury
4 Deceleration—Throttle closed and manifold vacuum above that obtained under normal idle conditions*

Table II provides information on a typical automobile exhaust, showing the concentrations of contaminants, exhaust gas volumes and other pertinent data in the four cycles of automobile operation. The actual emissions from any given automobile may vary widely from the figures shown, depending upon transmission type, condition of the vehicle, size of the engine and the manner in which the vehicle is operated.

Tests have been run on a route which is representative of average Los Angeles County driving and the time spent in each of the four driving cycles recorded. These data, together with data on exhaust gas volumes and contaminant concentrations for each cycle can be used to estimate the average contribution per cycle as a percent of the total. This is shown in Table III.

Methods for Controlling Exhaust Emissions

Efforts to control the smog forming constituents of automobile exhaust gases have occupied a great deal of the attention of control agencies, research groups, the automobile industry, the federal government and independent inventors and engineering firms. The great part of this effort has been directed toward reducing or eliminating hydrocarbons. Some study has also been directed toward the emissions of oxides of nitrogen. A number of approaches to the exhaust contaminants have been worked out and devices built following several different principles for control.

Methods for the control of hydrocarbons and other organic components

* For those automobiles in which, because of valve timing, a higher manifold vacuum is possible during low speed steady state cruising than at idle, the manifold vacuum at idle is simulated by cruising on a level road at a constant speed of approximately 30 mph.

may be classified as follows:

1 Fuel modifications
2 Deceleration fuel shutoff devices
3 Vacuum breakers and vacuum limiters
4 Oxygen and ozone enrichment of air supply
5 Fuel atomizers and vaporizers
6 Carburetor isolating valves
7 Exhaust gas recirculation
8 Fuel injection
9 Exhaust control devices
  Exhaust gas purifiers
  Afterburners (direct flame and catalytic)
10 Radical changes in engines

Each of the above approaches will be discussed, giving the principle upon which the method is based, the results of experimental work and tests on devices using the principle, and the promise shown by the method as a solution for the auto exhaust problem.

1. *Fuel Modifications*

Reduction of Olefin Content. Fuel modification methods will be discussed only briefly here since this paper is concerned primarily with control devices. Since, however, there has been a great deal of work directed toward solving the smog problem by fuel changes, and since there has been a tremendous amount of discussion and controversy on the subject, some brief comments will be made. Foremost amongst the methods of fuel modification at the present time is that of reducing olefins. It has been shown beyond any doubt that olefins are the most important class of hydrocarbons undergoing reactions in the air to form smog.[7] It has also been shown that within certain limits, concentrations of olefins in the exhaust gases will vary directly with the concentrations of olefins present in the gasoline used as a fuel.[8] It has also been shown that the eye irritation response to irradiated exhaust gases is a function of the olefinic content of the gasoline. Because of these facts, the Los Angeles County Air Pollution Control District has proposed the enactment of rules to limit the olefins in gasoline sold in the Los Angeles County area.

Radical Changes in Fuel Composition. Many proposals have been studied for radically altering the fuel composition in order to reduce smog forming contaminants. Chief among the suggested changes are:

1 Use of alcohol
2 Use of liquefied petroleum gases (propane, butane, or mixtures of these)

It is evident that the exhaust gases formed from burning alcohol in an internal combustion engine would give a material difference in exhaust gas composition from that obtained when using gasoline. This statement would apply to the minor components which contribute to smog as well as to the major products of combustion such as carbon dioxide and water. A few studies on the eye irritating effects of exhaust gases with alcohol as a fuel have shown rather anomolous results. In some cases eye irritation has been obtained; in other cases, none.[9] Since the practical problem of supplying alcohol on a large scale and at a reasonable cost as a motor fuel seems to be remote at the present time, this line of attack on the problem has not been pursued.[10] There are plans, however, to make some further studies to compare the smog forming potential of alcohol exhaust with that of conventional gasoline fuels.

Comparative tests have been run on engines equipped with LPG (liquefied petroleum gas) and gasoline. In general, LPG produces greater emissions of hydrocarbons, measured as n-hexane, than gasoline fuel during all phases of engine operation. The production of oxides of nitrogen is essentially the same with LPG or gasoline. Lesser amounts of carbon monoxide and aldehydes are formed with LPG. Since the objectionable odors connected with a motor vehicle are directly related to the aldehydes in the exhaust, it would then follow that LPG equipment would be less offensive, from an odor standpoint, than would gasoline engines. The use of LPG, in limited tests, has also shown a reduction in exhaust olefins consisting of four or more carbon atoms. No definitive conclusions concerning the overall smog reduction potential of LPG fuels can be formulated until further detailed studies have been conducted. Large scale use of LPG for motor vehicles would offer many economic and supply problems.[20]

Fuel Additives. Almost universally oil companies include additives in their gasolines. Some of these are well known through advertising, such as TCP, Boron and Petrox. The claims made for these do not have reference to their ability to reduce smog but to their effect in increasing power, preventing pre-ignition or reducing knocking. Tetraethyl lead is universally used in gasolines to increase octane rating along with other compounds to reduce oxidation and gum formation.

There are a great number of other fuel additives on the market which have been submitted as a method of reducing smog from auto exhaust. The claims made for the additives in this regard are quite varied. Some of the principles upon which reduction of hydrocarbons are claimed are as follows:

1 Improving combustion by catalytic action. Some gasoline additives which have been submitted for study are claimed to have a catalytic effect on the combustion processes so that complete combustion can occur.
2 Improving engine performance by removing carbon, lacquer and gum.
3 Improving carburetor performance by removing deposits in the carburetor.

A number of tests have been made on fuel additives to determine their effect on exhaust content. No fuel additive thus far tested has shown any ability to change materially the exhaust gas composition or to reduce the hydrocarbons present in the exhaust. Since incomplete combustion in the gasoline engine is a result of the inherent conditions present, such as combustion chamber cooling wall and exhaust gas dilution effects, it is doubtful that gasoline additives will offer a solution to the exhaust gas problems. Certainly the usual gum solvent types of additives show no promise.

2. *Deceleration Fuel Shutoff Devices*

It has been shown that the concentration of hydrocarbons and other organic compounds in the exhaust gases are much higher during the deceleration cycle of operation than during any of the other three cycles and that as a consequence, a relatively large percentage of the smog forming contaminants in the total exhaust output is contributed during the deceleration cycle. This has led many investigators and inventors to turn toward deceleration fuel shutoff devices as a means of reducing the smog forming potential of auto exhaust. In general, these devices, as illustrated in Fig. 2, are designed to shut off the flow of fuel through the idle circuits during the period of deceleration and to allow the fuel flow to resume when idling conditions are reached. A needle valve operating either upon the intake manifold vacuum or through an electrical control will close the idle circuit during deceleration. Devices of this type based upon the intake manifold vacuum are usually through a spring-loaded diaphragm arrangement. In an electrically activated device the needle valve is usually moved by a solenoid energized through a series of switches. Generally one switch is placed on the throttle and another switch in series is actuated by some mechanism related to engine speed. When both switches are closed, the current through the solenoid forces the needle valve to close the idle fuel port.

Deceleration fuel shutoff devices of the type described must operate within very close tolerance limits if they are not to interfere with the best functioning of the engine. In general, malfunctioning of these devices will cause the engine to stall on idle. This will happen if there is too much lag in the response to the control mechanism whether this is ac-

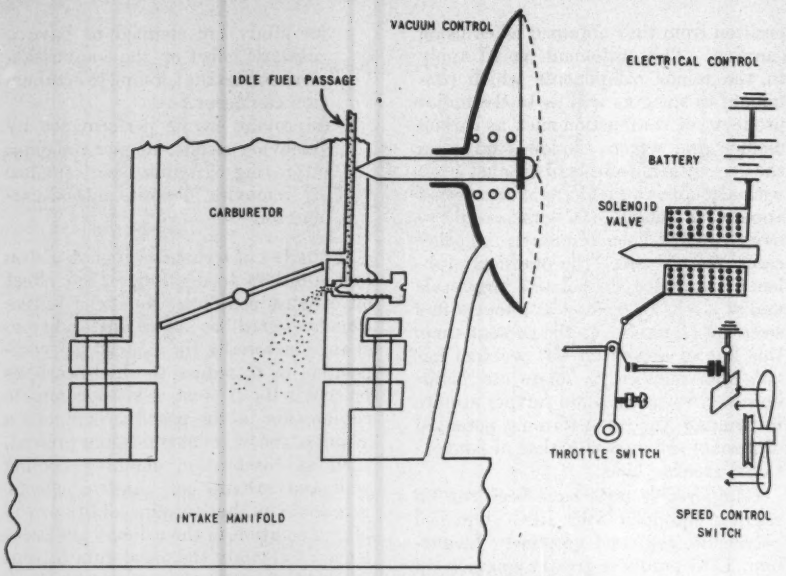

Fig. 2. Deceleration fuel shut-off device.

tuated by vacuum or electrical controls.

Fuel deceleration devices function only during the deceleration cycle and do not materially affect the operation of the idling, cruising or acceleration cycles.

Deceleration fuel shutoff devices have shown efficiencies in the reduction of hydrocarbons of higher than 90 per cent when tested on a dynamometer under steady state conditions. Road test efficiencies under the deceleration conditions are considerably lower than this, however. In one case a device showing 90 per cent efficiency on a dynamometer test showed only about 50 per cent under road tests. The wetting and drying effect of the intake manifold during transient cycle conditions is the major cause of this reduction in effectiveness. During long deceleration periods, the drying effect of the manifold is negligible when compared to the unburned hydrocarbon output coming from the carburetor idle circuit. On extremely short decelerating periods (such as shifting from one gear to another) the drying effect of the manifold may produce as much unburned material as produced by the carburetor. For this reason, the final evaluation of deceleration fuel shutoff devices must be under road test conditions. Under road conditions, on the deceleration cycle only, fuel shutoffs have shown hydrocarbon reductions in the 50–60 per cent range.

3. Vacuum Breakers and Vacuum Limiters

During the decleration cycle, when the hydrocarbon emissions in the exhaust gases are at their highest concentrations, the intake manifold vacuum is also very high—running from 20 to 25 in. of mercury. Under these conditions of high vacuum, combustion is intermittent, thus allowing much of the fuel to be exhausted essentially unchanged. This has suggested to many the expedient of preventing the vacuum from reaching these high values by some control device. The devices fall into two categories—vacuum breakers and vacuum limiters. Vacuum breakers have enough capacity for air admission into the intake manifold to drop the vacuum effectively to zero; while vacuum limiters, bleeding in only a relatively small quantity of air, will keep the vacuum from rising above a predetermined value.

Vacuum Breakers. The vacuum breaker, as illustrated in Fig. 3, can very effectively reduce exhaust contaminants because it eliminates air flow through the carburetor during deceleration, thereby effectively shutting off the flow of fuel. The mechanical problems involved in designing a successful vacuum breaker are rather formidable since it must incorporate a large valve with extremely fast response to controls—rapid opening and shutting action. For installation of this type of device, a large spacer between the carburetor and intake manifold is generally needed. The increased height of the carburetor cannot be accommodated under the modern low silhouette hood.

Tests made on vacuum breaker types of control have shown efficiencies on steady state deceleration in the range of 68–84 per cent. Since this efficiency has been exceeded by simpler and cheaper devices such as the deceleration fuel shut-off device, the vacuum breaker will probably not be a serious contender for reducing exhaust emissions.

Vacuum Limiters (air bleed type). Manifold vacuum limiters are of two general types. One lowers the vacuum by bleeding a limited amount of air into the intake manifold. The other lowers the vacuum by opening or holding open the carburetor's throttle.

The air bleed type of vacuum limiter, as illustrated in Fig. 4, actually causes greater emissions of hydrocarbons during deceleration than normal operation without the device. This occurs because the addition of air further dilutes a fuel mixture already diluted with exhaust gases, resulting in even less burning than would normally occur during decleration.

The hydrocarbon emissions are increased by a factor of 1.5 to 3.5 during deceleration by this type of limiter.

Vacuum Limiters (dashpot type). The dashpot type of vacuum limiter, as illustrated in Fig. 5, reduces the manifold vacuum by retarding the closing action of the throttle generally for a period of from two to four seconds. Any longer damping action will have an adverse effect on the driving performance of the vehicle. In essence, the dashpot, by holding the throttle open, converts a portion of the deceleration to a cruise cycle. This results in

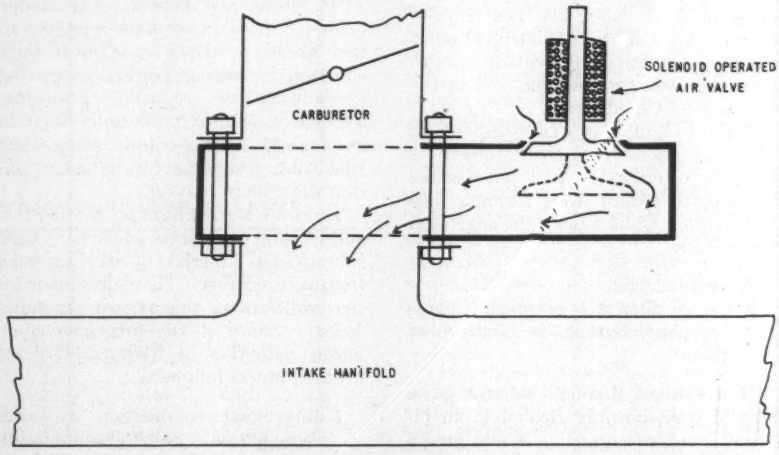

Fig. 3. Vacuum breaker.

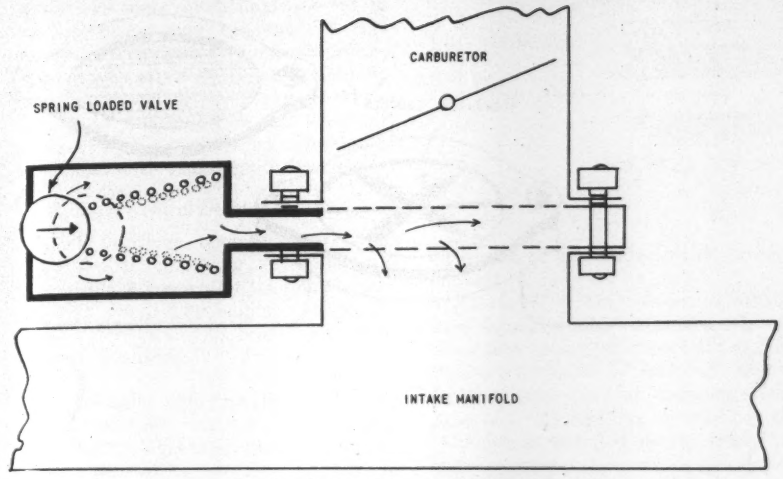

Fig. 4. Vacuum limiter—air bleed type.

proportional lowering of the hydrocarbon emissions. When the retarding of the dashpot is completed, the device is ineffective. Therefore, during long periods of deceleration, the device would be inoperative a large proportion of the time.

The reduction of emissions of contaminants through the use of the throttle dashpot alone will vary materially with the type of transmission and manner of operation of the vehicle.

Vacuum Limiters (throttle cracker type). This type of vacuum limiter, shown in Fig. 6, was introduced to overcome the limited effectiveness of the dashpot. The throttle cracker type "cracks" the throttle open on deceleration sufficiently to lower the manifold vacuum to approximately 22 in. of mercury. The throttle remains open regardless of the length of deceleration until the vehicle speed diminishes and the vacuum finally goes below 22 in. The throttle then gradually closes to the normal idling position.

With this system the retarding effect of the engine is adversely affected. In performance tests many drivers rated the throttle cracker as being unsatisfactory, while others hardly noticed the reduction in retarding effect. In most cases a driver who was decelerating from higher speeds found the device "unsatisfactory," but those driving at slower speeds around town had no adverse comments. The brake lining wear and fuel mileage would also be adversely affected with the throttle cracker.

Several accessories have been applied to the basic throttle cracker; one such accessory would limit the function of the device to any predetermined time—say 14 or 15 sec. Thus, in a prolonged deceleration (over 14 or 15 sec) such as might be encountered in going down a long steep grade, the device would be rendered inactive, and the vehicle would have its original retarding ability.

Another accessory would render the device inoperative in any transmission range except "drive." Thus when using a lower transmission range for increased retarding ability the device would be inoperative. From a safety standpoint, these additional features should be a part of the basic device. Throttle crackers have shown efficiencies on the deceleration cycle in the range of 60 per cent in ability to reduce hydrocarbons. This value was determined under road conditions.

4. Oxygen and Ozone Enrichment of Air Supply

Efforts to obtain more complete combustion in the internal combustion engine, and thereby less contaminants in the exhaust gases, by means of addition or alteration to the air supply have been tried by several investigators. These involve enrichment of the air by ozone and enrichment of the air by oxygen. Ozone and oxygen generators, which depend on the electrical system of the automobile for their energy, have been tested. These have proved to produce such negligible quantities of oxygen or ozone that the combustion mixture is not appreciably changed and the effect on the exhaust gases is negligible.

While enrichment of the combustion mixture with larger amounts of oxygen

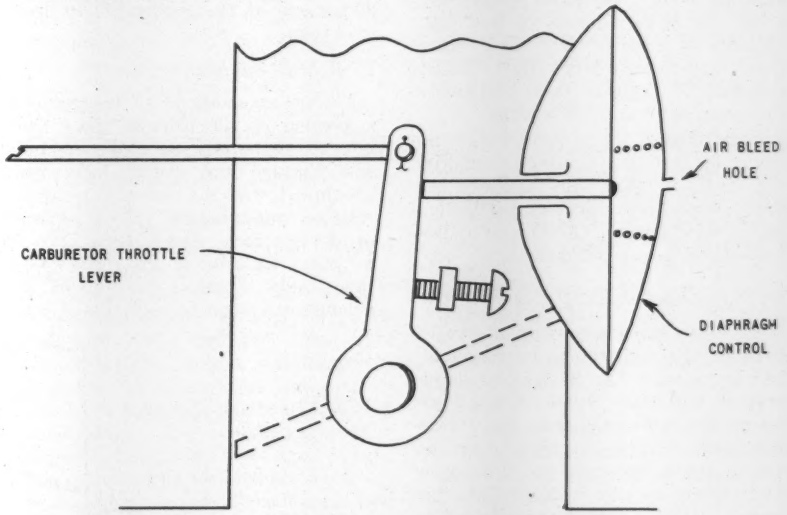

Fig. 5. Vacuum limiter—dashpot type.

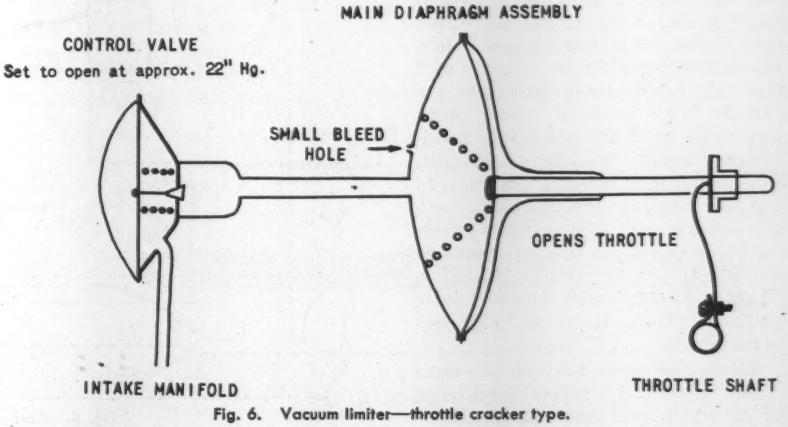

Fig. 6. Vacuum limiter—throttle cracker type.

could conceivably cause more complete combustion and thus reduce exhaust contaminants, the practical considerations involved preclude any optimistic appraisal of this form of control. Obtaining oxygen in sufficient amounts would be costly and impracticable. Also the high temperatures resulting from enriching the air with oxygen would have an adverse effect on the exhaust valves and other parts of the engine.

5. Fuel Atomizers and Vaporizers

This classification, as illustrated in Fig. 7, includes all devices that are designed to promote better atomization or vaporization of the liquid particles coming from the carburetor. The proponents of these devices claim improved combustion resulting from a more homogeneous air and fuel mixture. Many consist of some type of mechanical whirling member which receives its motion from the velocity of the incoming air. This moving member acts as a "chopper" for reducing the size of the gasoline particles. Other types simply use a screen, with perhaps some air bleed holes, which presumably break the large droplets of fuel into particles of smaller size. Still other types apply heat from the exhaust manifold to vaporize more effectively the incoming air and fuel mixture.

Regardless of the specific design, no device for further atomizing or vaporizing the fuel mixture thus far tested has shown any improvement in combustion as identified by CO_2, CO, O_2 and hydrocarbon exhaust concentrations.

6. Carburetor Isolating Valves

This classification consists of a valve between the carburetor and manifold, as illustrated in Fig. 8. During deceleration, the valve closes off and "isolates" the carburetor from the intake manifold. In closing completely, no air is drawn through the carburetor and, hence, no fuel is drawn into the engine. With no air being allowed to enter the engine through the carburetor, the manifold vacuum will be higher than during normal deceleration. Since this condition may draw more oil past the valve guides and rings into the cylinder with resulting smoke, some sort of air bleed into the intake manifold is generally employed in conjunction with the isolating valve. In lieu of bleeding the manifold with atmospheric air, the exhaust gases have, in some instances, been recirculated to the intake manifold. This system reduces the exhaust volume and thus adds to the overall efficiency of the device.

Service life tests have shown some difficulty with the proper functioning of the valve mechanism in the device over extended periods. This applies particularly to the exhaust bleed type as valves must operate in a corrosive atmosphere. Carburetor isolating valves have shown efficiences of approx. 60 per cent on the deceleration cycle in road tests.

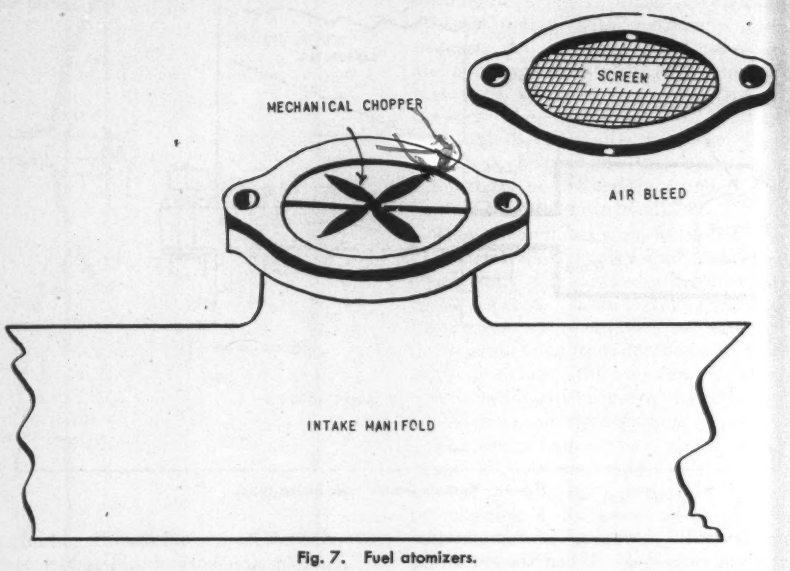

Fig. 7. Fuel atomizers.

7. Exhaust Gas Recirculation

Devices or methods for recirculating a portion of the exhaust gases back into the carburetor or intake manifold and through the engine have been attempted, with the idea of burning the residual contaminants. These methods or devices have shown very little or no effect on exhaust gas composition. Since only a small portion of the exhaust gases can be recirculated without adversely affecting the engine operation, this general method offers little promise for satisfactory control of hydrocarbon emissions.

8. Fuel Injection

Fuel injection, as applied to vehicles of American manufacturers, shuts off the fuel flow on deceleration. For this reason, fuel injection will undoubtedly be in the same general range of efficiency as the deceleration fuel shutoff. With fuel injection at the inlet port, practically no delay occurs between the time of injection and time the fuel mixture reaches the cylinder. Thus the problem of properly resuming idling is minimized. It would be difficult, however, for a fuel injection

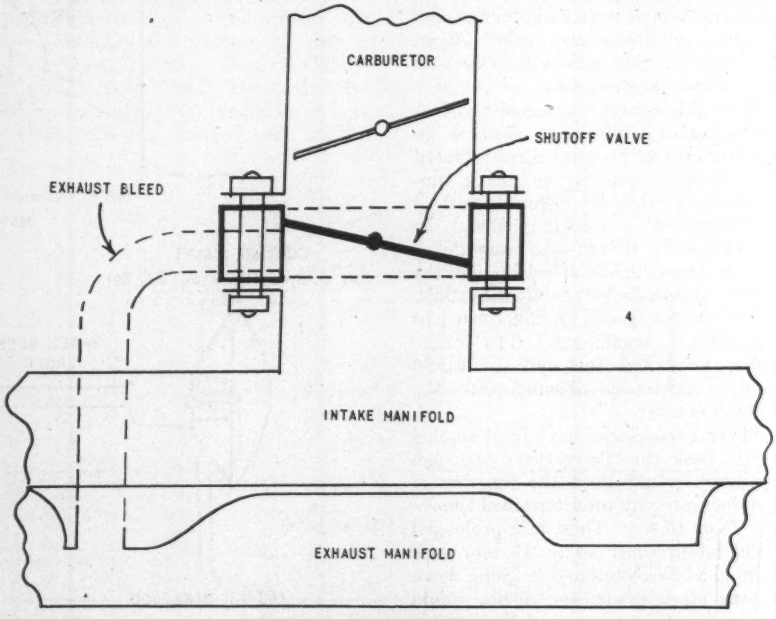

Fig. 8. Carburetor isolating valve.

system to show much improvement in air-fuel ratios over conventional carburetors. The conventional carburetor, in most cases, delivers an extremely efficient air-fuel mixture. It is questionable that fuel injection, at least for some time to come, will be competitive as an automotive smog control device.

9. Exhaust Control Devices

These devices operate under the principle of removing contaminants from exhaust gases after they have been emitted from the engine. Exhaust control devices can be broken into two general categories:

1 Exhaust gas purifiers (water scrubbers, chemical scrubbers, filters, adsorbers and centrifugal cleaners)
2 Afterburners (direct flame and catalytic)

Exhaust Gas Purifiers. Of all the types of controls for automobiles, the class which seems to have the most appeal for independent inventors are those involving purifying the exhaust gases through some chemical or physical means. Scrubbers using water and chemicals of various types have been built in many shapes and sizes. Filters designed to remove particulate matter are submitted for evaluation at frequent and regular intervals. Since the components in automobile exhaust which are the smog forming contaminants are, in the main, gaseous hydrocarbons which are insoluble in water, it is apparent that water scrubbing offers no effective means of control. Scrubbers using chemicals are equally ineffective since up to this time no solution capable of materially reducing the hydrocarbon content has been found. Even if reactive chemicals capable of doing this were available, the size of equipment necessary for effective contact of the solution with the exhaust gases, the problems of disposal of spent solutions, the expense of the frequent replacement of chemicals and practically insurmountable enforcement problems render this approach to control quite untenable.

Filters and adsorbers have somewhat the same objections, with the additional one that particulate matter in the exhaust tends to clog the materials used and thus build up back pressures to an objectionable degree. A few devices based on the centrifuging of the exhaust gases have been built. These usually operate on the erroneous assumption that the particulate matter in the exhaust gases is the important contaminant, or under incorrect claims that contaminant gases can be separated out. None of the devices categorized here as exhaust gas purifiers seem to have any remote possibility of being successful in the control of automobile exhaust.

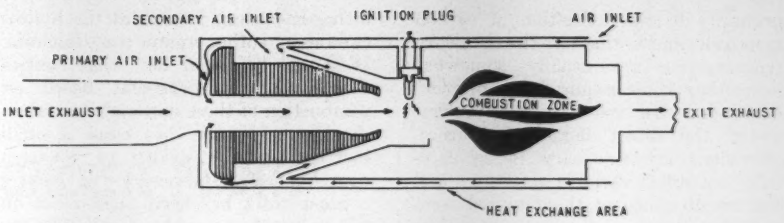

Fig. 9. Exhaust afterburner.

Afterburners. Since the contaminants in automobile exhaust gases are for the most part unburned or partially burned hydrocarbons, it is apparent that a feasible principle for reducing these contaminants lies in completing the combustion initiated in the engine to convert these contaminants into carbon dioxide and water. This principle underlies the class of control devices which we call afterburners. Afterburners may be divided into two types—the direct flame afterburner, shown in Fig. 9, and the catalytic muffler, shown in Fig. 10.

The principal difference between the catalytic muffler and the direct flame afterburner is the temperature required for the complete combustion of the contaminants. With a catalyst present, generally speaking, considerably lower temperatures will suffice to completely oxidize the combustible material. Thus the principle of maintaining the combustion reaction should be easier to achieve in a catalytic type afterburner.

Direct Flame Afterburner. While in principle the destruction of exhaust gas contaminants is quite simple, the actual designing of an effective afterburner has proved to be a very difficult task. The difficulty arises from the extremely variable conditions obtained in the exhaust gas flow, most of which are not conducive to maintaining combustion. The combustion process requires adequate fuel and oxygen supply, velocities low enough to prevent extinguishment of the flame, and maintaining of temperatures above the ignition point. To accomplish this in a direct flame afterburner requires closely controlled variable air input into the afterburner, adequate insulation and heat exchange of the incoming and outgoing exhaust gases, ignition devices, and properly controlled exhaust velocity in the afterburner. It has been demonstrated that an afterburner can be built to meet all these requirements, but as yet none have been designed which can be considered as commercially acceptable. In addition, an afterburner must be rugged enough to maintain a long operating life under the extreme conditions encountered. Further requirements for a commercially acceptable device would include reasonable cost and dimensions which would allow it to replace the conventional muffler.

A number of afterburners have provided for sufficient fuel to maintain combustion through all cycles by the direct introduction of fuel, usually gasoline, into the device. While this is a practical way of insuring continuous operation during all the operating cycles of a vehicle, it is extravagant in fuel consumption.

An interesting variant of the direct flame afterburner has been studied. This variant can be called a deceleration afterburner since it is designed to burn only during the deceleration cycle of the engine. During deceleration the ignition circuit of the engine is shut off, thus providing a very combustible mixture to the device. One problem of the device is the intermittent burning and backfiring. This has apparently been overcome by providing flame arresters.

Catalytic Mufflers. In the catalytic muffler, exhaust gases, with sufficient added air for complete oxidation of the contaminants, are brought into intimate contact with a catalytic material. A sufficiently high temperature must be maintained to insure continuous and complete oxidation of the contaminants to carbon dioxide and water. In some cases the oxidation proceeds

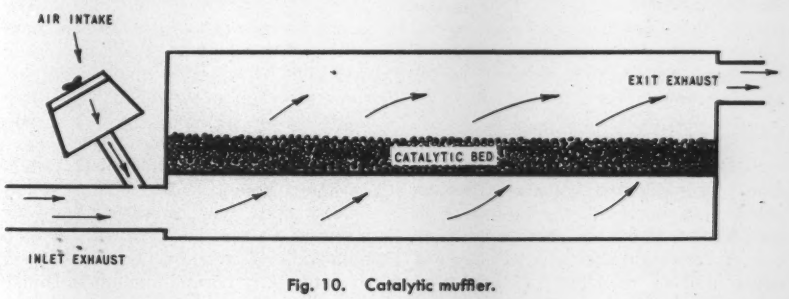

Fig. 10. Catalytic muffler.

primarily to the formation of carbon monoxide, and in this case the necessary temperatures are usually somewhat lower than those required for complete oxidation. In the catalytic muffler, as in the direct flame afterburner, provisions are necessary for a carefully controlled variable air supply and the maintenance of the required temperatures for continuous operation. The latter condition usually requires insulation of the muffler. The velocity of flow through the catalytic muffler is not as critical as with the direct flame afterburner, and successful operation can probably be maintained without the necessity of heat exchange between incoming and outgoing exhaust gases. One very important requisite for a catalytic muffler is long life of the catalyst. This means that a successful catalyst must not be adversely affected by the lead compounds present in exhaust gases. The catalyst material or the base materials which carry the catalyst must be sufficiently strong mechanically to resist attrition over a long period of operation. Catalysts which thus far have been demonstrated to be active in promoting the oxidation of hydrocarbons in exhaust gases include some of the precious metals such as platinum, and metallic oxides such as vanadium oxides.

Since direct flame afterburners and catalytic mufflers treat the entire exhaust gas output of a vehicle, their efficiencies in eliminating exhaust gas contaminants can be expected to be much higher, in the 90 per cent and above range, than the efficiencies of devices which operate only on the deceleration cycle. Furthermore, the afterburner or catalytic muffler is more or less independent of the operation or mechanical condition of the engine. Generally speaking, then, it appears that the afterburner or catalytic muffler may ultimately prove to be the method of choice for control of hydrocarbons in the exhaust gases.

10. Radical Changes in Engines

Many proposals are made for controlling vehicular exhaust gases by radically new engine designs such as the gas turbine engine, the free piston engine, electric battery motor drives, and others. Since the problem confronting us at the present time is the nearly three million gasoline engines being driven in Los Angeles today, we feel that the radically new engine approach is something for the future.

Control of Oxides in Nitrogen

Since the smog ultimately produced from motor vehicle exhaust involves the interaction of organic compounds with oxides of nitrogen, studies have been oriented toward the possibility of controlling or reducing the oxides of nitrogen content as well as the hydrocarbons and other organic contaminants. It should be noted here that control devices for hydrocarbons, based on combustion of these materials to carbon dioxide and water, may cause a small increase in the oxides of nitrogen content of exhaust gases.

Some work has been carried out on the reduction of oxides of nitrogen by catalytic decomposition. The results indicate that this method would not be successful under any reasonable size and temperature limitations which the motor vehicle would impose.

Production of oxides of nitrogen is at a maximum under slightly higher than stoichiometric air-fuel ratios.[11] In general, this is what would be expected since these mixtures produce high temperatures which promote the formation of oxides of nitrogen. Enriching the fuel mixture has been shown to reduce oxides of nitrogen, but this is accompanied by an increase in hydrocarbon emissions. With the advent of a satisfactory means of hydrocarbon removal, the use of fuel enrichment for removal of oxides of nitrogen is a definite possibility.

The addition of water to the air-fuel mixture has a noticeable effect on the combustion processes in the engine. The effect appears to be mainly in the reduction of the high peak temperature and pressure developed during combustion.

This would reduce the formation of oxides of nitrogen as well as detonation or "pinging." Tests carried out on water injection have shown no decrease in the hydrocarbon content but it has been shown to decrease the concentration of oxides of nitrogen in the exhaust gases. The effect is not too significant, however, until the amount of water injected is equal to about one-half the gasoline consumption. At this high water injection rate the power output is adversely affected.

Control of Other Contaminants

Carbon monoxide and smoke, as mentioned previously, are air contaminants found in automobile exhaust gases. Carbon monoxide is a toxic gas, but it is not eye irritating, does not reduce visibility, is not detectable by odor and does not enter into the photochemical smog reactions. The current concentrations of carbon monoxide in the Los Angeles atmosphere are well below toxic limits. Therefore, no attempts have as yet been made by the APCD to control specifically this contaminant from automobile exhaust. It should be noted, however, that the direct flame afterburner and some types of catalytic mufflers reduce or eliminate carbon monoxide by combustion to carbon dioxide. Any normal amount of smoke may also be eliminated by an afterburner or catalytic muffler.

Conclusions

On the basis of the extensive program of review, evaluation and physical testing of many types of automotive control devices and methods, it now appears that essentially complete hydrocarbon control must await development of a practical afterburner, either catalytic or direct flame. Lesser degrees of control, however, may be achieved through the use of devices operating essentially on the deceleration cycle. Fuel modification can be expected to decrease the smog forming capability of exhaust gas.

Neither deceleration type devices nor fuel modification alone, however, appear to offer an ultimate solution to the problem. Perhaps future combinations of methods and devices such as the combining of fuel enrichment with an afterburner will prove effective.

REFERENCES

1. Second Technical and Administrative Report on Air Pollution Control in Los Angeles County 1950–51. Air Pollution Control District, County of Los Angeles, p. 28.
2. A. J. Haagen-Smit, E. F. Darley, M. Zaithlin, H. Hall, and W. M. Noble, "Investigation on Injury to Plants from Air Pollution in the Los Angeles Area," *Plant Physiology*, **27**, No. 1, pp. 18–34 (January, 1952).
3. R. L. Chass, R. G. Lunche, N. R. Shaffer, and P. S. Tow, "Total Air Pollution Emissions in Los Angeles County," Paper 59–58, APCA 52nd Annual Meeting (June, 1959).
4. Section 426.2, Health and Safety Code, State of California.
5. W. A. Daniels, "Flame Quenching at the Walls of an Internal Combustion Engine," 6th International Symposium on Combustion, Yale University (August, 1956).
6. W. Linville and Y. S. Yee, "A Preliminary Report on Gasoline Evaporation Losses," Air Pollution Control District, County of Los Angeles (January, 1959).
7. P. P. Mader, J. Gliksman, M. Eye, and L. A. Chambers, "Photochemical Formation of Air Contaminants from Automobile Exhaust Vapors," *Industrial and Engineering Chemistry*, **50**, p. 1173 (August, 1958).
8. P. P. Mader, M. Eye, J. A. Orcutt, and L. A. Chambers, "Effects of Fuel Olefin Content on Composition and Smog Forming Capabilities of Engine Exhaust," Air Pollution Control District, County of Los Angeles, Interim Report No. 2.
9. APCD Automotive Combustion Laboratory Report LT-11 (May, 1958).
10. "Feasibility of Control Methods for Automobile Exhaust," Southwest Research Institute, Air Pollution Foundation Technical Report No. 10 (August, 1955).
11. G. J. Nebel and M. W. Jackson, "Some Factors Affecting the Concentration of Oxides of Nitrogen in Exhaust Gases from Spark Ignition Engines," J. APCA, **8**, No. 3, p. 213 (November, 1958).

Control of ASPHALTIC CONCRETE PLANTS in Los Angeles County*

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Introduction

The phenomenal growth of population in Southern California during the last two decades has resulted in large demands for asphaltic concrete. To meet these demands, in Los Angeles County alone, 48 asphaltic concrete plants have been built which produce an average of 14,000 tons per day.

Prior to the installation of well-designed air pollution control equipment, dust losses from asphaltic concrete plants were nearly 25 tons per day. In 1949, the Air Pollution Control District of Los Angeles County adopted a rule which limited the discharge of dust from each of these plants to 40 pounds per hour.[1] To meet this prohibition, it became necessary to install dust collection equipment capable of high collection efficiencies. This was accomplished by the use of centrifugal or impingement type scrubbers which provided collection efficiencies, in most cases, of 90 percent or greater. The design of these control devices has improved over the years, and as described later in this paper, total emissions have decreased substantially in spite of increased production.

Description of Basic Equipment

Generally, an asphaltic concrete plant consists of a rotary dryer, screening and classifying equipment, an aggregate weighing system, a mixer, storage bins and conveying equipment. Sand and aggregate are charged from bins into a rotary dryer. The dried aggregate at the lower end of the dryer is mechanically conveyed by a bucket elevator to the screening equipment where it is classified and dumped into storage bins. Weighed quantities of the sized products are then dropped into the mixer along with asphalt where the batch is mixed and dumped into awaiting trucks for transportation to the paving site. The combustion gases and fine dust from the rotary drier are exhausted through a precleaner which is usually a single cyclone, but twin or multiple cyclones and other devices are also used. The precleaner catch is then discharged back into the bucket elevator where it continues in process with the main bulk of the dried aggregate. The air outlet of the precleaner is vented to air pollution control equipment.

Air Pollution Control Equipment

In Los Angeles County two principal types of control equipment have evolved from many types employed over the years—the multiple centrifugal type spray chamber and the baffled type spray tower. Of these two types, the multiple centrifugal type spray chamber (Fig. 1) has proved to be the more efficient. It consists of two or more internally fluted cylindrical spray chambers in which the dust-laden gases are admitted tangentially at high velocities. Each of these chambers is identical in size and has dimensions approximately

Fig. 1. Typical multiple centrifugal type spray chamber serving an asphaltic concrete plant.

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26, 1959, Los Angeles, Calif.

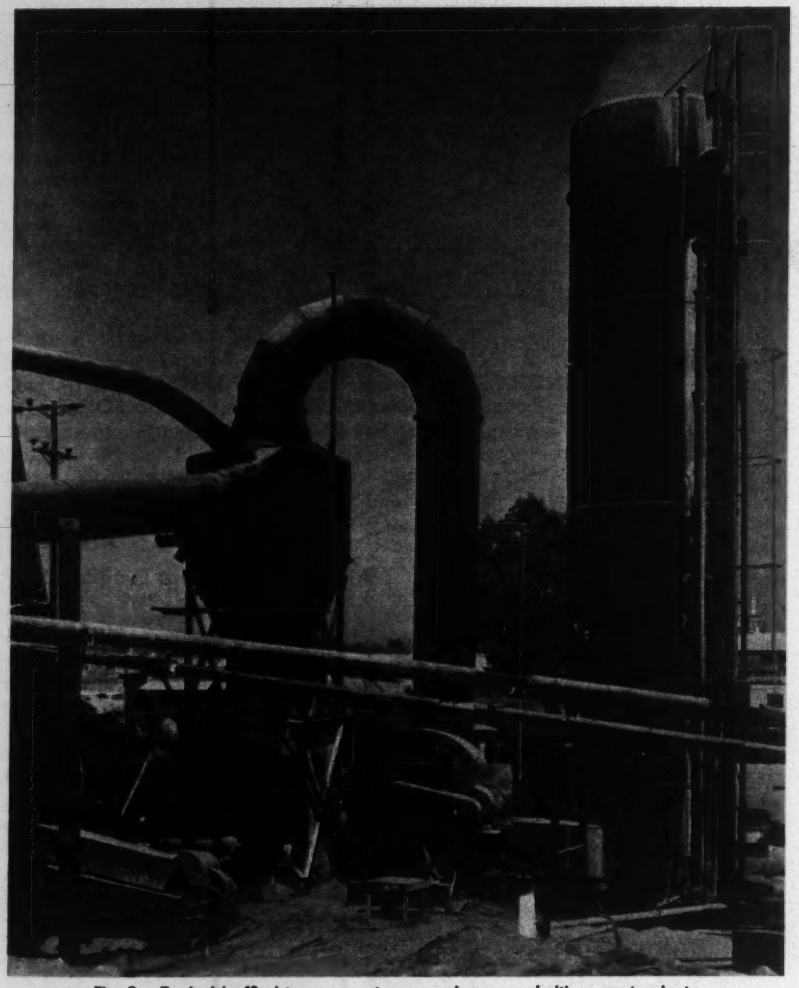

Fig. 2. Typical baffled type spray tower serving an asphaltic concrete plant.

6 ft diam x 15 ft long. Usually five to 10 spray nozzles are located evenly spaced within each chamber. Water rates to the nozzles are usually in the range of 70 to 250 gpm at 50 to 100 psi and the water generally is not recirculated. In the baffled type spray tower (Fig. 2), there have been many variations in designs, but fundamentally, each consists of a chamber which is baffled to force the gases to travel in an S-shaped pattern, encouraging impingement of the dust particles against the sides of the chamber and the baffles. Water spray nozzles are located between the baffles and water rates through the spray heads usually vary between 100 to 300 gpm at 50 to 100 psi.

In addition to venting the dryer, the dust collection system also ventilates several other dust sources which include: (1) the lower end of the dryer where the stationary burner box attaches to the rotary dryer; (2) the aggregate screening and classifying system; (3) the bucket elevator; (4) the aggregate storage bins; and (5) the weigh hopper.

Asphaltic concrete plants vary in size with the majority capable of producing 100 to 150 tons per hour. However, in the last two or three years, several plants have been installed in Los Angeles County which are classified as 6000-pound plants, capable of producing 200 to 250 tons per hour.

The major source of dust originates from the rotary dryer. Very little work has been done in the study of dust emissions from rotary dryers. Friedman and Marshall[2] obtained data showing that dryer dust emissions, expressed as percent of feed, increase with air mass velocity, increase with increasing rate of rotation, are independent of dryer slope, and decrease with increasing feed rate. The absolute amount of dryer

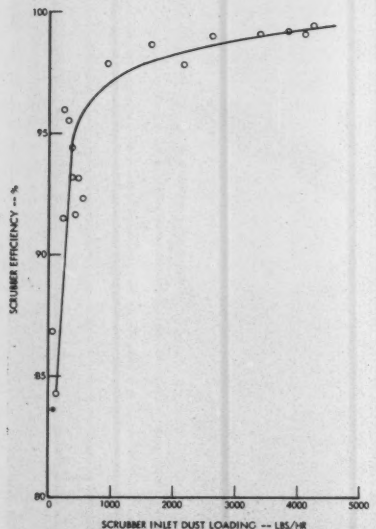

Fig. 3. Relationship between scrubber inlet dust loading and scrubber collection efficiency.

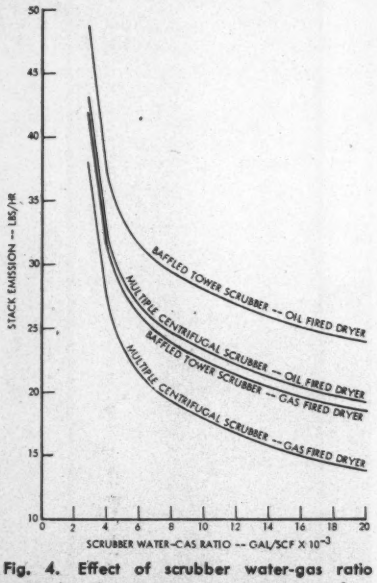

Fig. 4. Effect of scrubber water-gas ratio on stack emissions at average aggregate fines rate in the dryer feed.

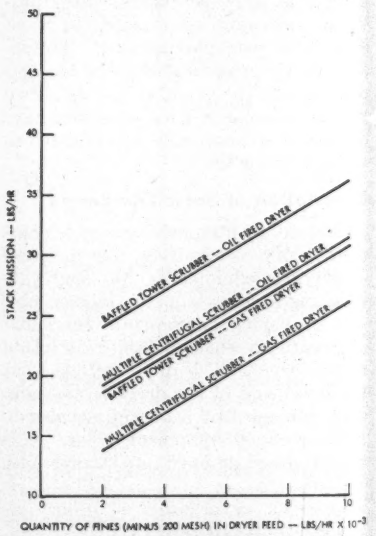

Fig. 5. Effect of aggregate fines rate on stack emissions at average water-gas ratio.

Table I—Test Data from Asphaltic Concrete Plants Controlled by Scrubbers

Test Number	Scrubber Inlet Dust Loading, Lb/Hr	Stack Emission, Lb/Hr, x_1	Aggregate Fines Rate,[a] Lb/Hr × 10^{-3}, x_2	Water-Gas Ratio, Gal/1000 scf, x_3	Log x_3	Type of Scrubber[b]	Type of Fuel	Production, Tons/Hr	Gas Effluent Volume, scfm
C-357	940	20.7	9.55	6.62	0.82	C	Oil	183.9	23,100
C-82	427	35.6	4.46	3.94	0.60	C	Oil	96.9	19,800
C-379	4110	37.1	8.35	6.38	0.81	C	Oil	174.0	26,200
C-355	2170	47.0	14.00	6.81	0.83	C	Oil	209.1	25,700
C-372B	121	19.2	2.29	10.99	1.04	C	Oil	142.9	18,200
C-372A	76	10.0	2.84	11.11	1.05	C	Gas	158.0	18,000
C-369	352	24.4	4.75	5.41	0.73	C	Oil	113.0	16,100
C-393	4260	26.9	4.05	12.01	1.08	T	Oil	92.3	19,500
C-354	—	27.8	6.37	6.10	0.79	T	Oil	118.4	7,720
C-185	1640	21.3	5.22	19.40	1.29	T	Oil	137.8	18,700
C-173	—	31.0	8.85	20.40	1.31	T	Oil	184.2	17,000
Outside lab.	—	33.5	7.52	11.01	1.04	T	Oil	144.6	23,700
C-379	3850	30.3	6.50	5.92	0.77	C	Gas	191.3	28,300
C-337	305	13.6	2.51	11.11	1.05	C	Oil	114.6	24,300
Outside lab.	—	21.1	3.73	7.28	0.86	T	Gas	124.4	15,900
C-234	372	21.2	2.53	5.70	0.76	T	Gas	42.0	17,200
C-426	2620	25.5	10.20	7.75	0.89	C	Oil	182.0	22,000
C-417	560	39.9	3.05	2.94	0.47	C	Oil	138.9	24,600
C-425	485	32.9	2.89	4.26	0.63	C	Oil	131.4	18,000
Outside lab.	—	25.5	6.59	6.60	0.82	C	Gas	131.7	18,200
C-385	212	17.5	4.89	4.56	0.66	C	Oil	174.3	20,000
C-433	266	11.0	5.96	8.12	0.91	C	Gas	114.5	19,600
C-422(1)	—	26.6	7.14	4.90	0.69	C	Oil	198.0	21,000
C-422(2)	—	37.0	3.34	3.02	0.48	C	Oil	152.0	22,200
C-418	3400	30.8	9.35	8.90	0.95	T	Oil	116.5	17,100
Totals		667.4	146.93		21.33				
Averages		26.7	5.9		0.85				

[a] Quantity of fines (minus 200 mesh) in dryer feed.
[b] C = Multiple centrifugal type spray chamber. T = Baffled tower scrubber.

dust, in weight per unit time, increases with feed rate. Dust emissions depend to a large extent on the particle size distribution of the dryer feed. While the dust from the rotary dryer is undoubtedly the greatest source, the dust collected from the vibrating screens, the bucket elevator, the bins and the weigh hopper is also considerable in quantity. In one plant, 2000 lb/hr of particulate matter containing 39.7 percent of 0 to 10 micron material was produced by these secondary sources.[3]

Study of Stack Test Data

In the process of granting permits to operate, many stack tests were conducted by the District to insure that each plant was operating in compliance with air pollution laws. As these data became available, a study was made to determine which variables were most significant in affecting emissions to the atmosphere. A preliminary observation disclosed that the water scrubber efficiency varied with the scrubber inlet dust loading as shown in Fig. 3. Higher dust collection efficiencies were obtained at the higher inlet dust loadings. Plants with less effective cyclone precleaning had, on the average, larger particles entering the water scrubber, and consequently better scrubber collection efficiencies were obtained. In fact, scrubber efficiency was so dependent upon the degree of precleaning that the effect of other variables on collection efficiency was completely masked in the available data. However, the fractional collection efficiency of particles larger than 10 microns in diameter proved to be 99.7 percent. Consequently, the variables and operating conditions which affect the amount and collection efficiency of the 0 to 10 micron fraction should be reflected in the absolute stack emissions. This was found to be the case. The magnitude of the stack emissions were found to depend mainly upon the scrubber water-gas ratio, the type of fuel used in the rotary dryer, the type of scrubber, and the quantity of minus 200-mesh material (minus 74 microns) processed in the dryer.[4] It would be expected that the particle size distribution of the minus 200-mesh fraction of the dryer feed would have a large effect on stack losses, but sufficient data were not available to investigate it.

Twenty-five source tests of asphaltic concrete plants were available (from some 115 tests which have been per-

Table II—Collection Efficiency Data for Scrubbers Serving Asphaltic Concrete Plants

Dust Particle Size, Microns	Test Report Series, C-393 Inlet, %	Outlet, %	Efficiency, %	Test Report Series, C-369 Inlet, %	Outlet, %	Efficiency, %	Test Report Series, C-372A Inlet, %	Outlet, %	Efficiency, %
0–10	13.0	99.3	95.2	76.4	79.9	92.8	78.0	83.0	85.0
10–20	71.1	0.0	100.0	6.3	3.8	96.0	18.0	5.0	96.2
20–44	9.6	0.0	100.0	2.8	2.0	95.0	2.0	1.0	93.3
44+	6.3	0.7	99.3	14.5	14.3[a]	93.1	2.0	11.0[a]	26.5

Dust Particle Size, Microns	Test Report Series C-372B Inlet, %	Outlet, %	Efficiency, %	Test Report Series C-422(1) Inlet, %	Outlet, %	Efficiency, %
0–10	91.0	82.0	85.7	80.4	73.2	—
10–20	9.0	3.0	99.4	18.6	5.1	—
1–44	0.0	2.0	—	1.0	4.5	—
44+	0.0	13.0[a]	—	0.0	17.2	—

[a] Microscopic examination indicated that the outlet samples were agglomerated.

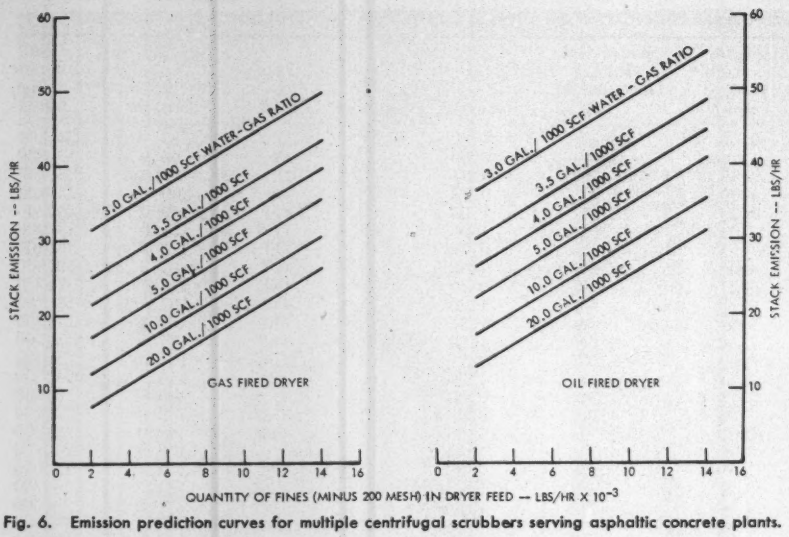
STACK EMISSION -- LBS/HR
3.0 GAL./1000 SCF WATER-GAS RATIO
3.5 GAL./1000 SCF
4.0 GAL./1000 SCF
5.0 GAL./1000 SCF
10.0 GAL./1000 SCF
20.0 GAL./1000 SCF
GAS FIRED DRYER
OIL FIRED DRYER
QUANTITY OF FINES (MINUS 200 MESH) IN DRYER FEED -- LBS/HR X 10⁻³

Fig. 6. Emission prediction curves for multiple centrifugal scrubbers serving asphaltic concrete plants.

formed since 1949) which had sufficient data to attempt to correlate the major variables affecting stack losses. Aggregate feed rates, screen size analyses, scrubber water and gas rates, as well as particulate matter emissions to the atmosphere were obtained during each of these tests. The data are tabulated in Tables I and II. The aggregate dryers were fired with PS 300 or heavier oils during 19 of the tests and natural gas fired during six. Seventeen of these tests were performed on multiple centrifugal-type scrubbers with spiral baffles and tangential entrances. The other eight tests were performed on simple baffled tower scrubbers. A curvilinear multiple correlation was required to represent the data satisfactorily. Ezekiel's[5] graphical procedure of successive approximations was used to fit the curves (see Appendix for correlation methods).

Effect of Variables on Scrubber Emissions

The effect of scrubber water-gas ratio on stack emissions is shown in Fig. 4, for multiple centrifugal type scrubbers and baffled tower scrubbers, with the aggregate fines rate (the minus 200-mesh fraction) held constant at the average. Low scrubber water-gas ratios are more than proportionately less effective than higher ratios. Possibly, the water rate was insufficient for good spray coverage for ratios in the lower ranges.

The effect of aggregate fines rate on stack emissions at constant water-gas ratio is shown in Fig. 5 for multiple centrifugal type scrubbers and baffled tower scrubbers. Stack emissions increase linearly with an increase in the amount of minus 200-mesh material processed.

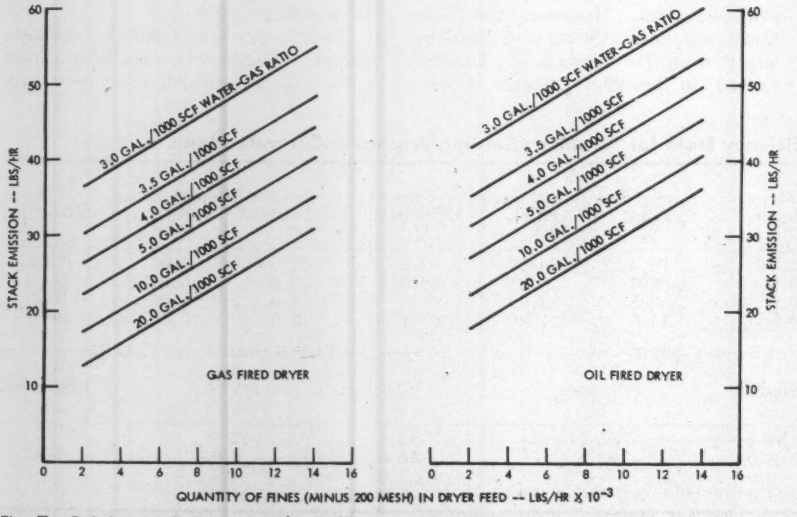
STACK EMISSION -- LBS/HR
3.0 GAL./1000 SCF WATER-GAS RATIO
3.5 GAL./1000 SCF
4.0 GAL./1000 SCF
5.0 GAL./1000 SCF
10.0 GAL./1000 SCF
20.0 GAL./1000 SCF
GAS FIRED DRYER
OIL FIRED DRYER
QUANTITY OF FINES (MINUS 200 MESH) IN DRYER FEED -- LBS/HR X 10⁻³

Fig. 7. Emission prediction curves for baffled tower scrubbers serving asphaltic concrete plants.

Stack emissions were 5.1 lb/hr higher when the dryer was oil fired, rather than gas fired. The difference is believed to represent particulate matter in or formed by the fuel oil, rather than additional dust from the dryer and mixer. It has been similarly observed that burning heavy fuel oils in other kinds of combustion equipment results in higher emissions of particulate matter. For example, glass furnaces discharge significantly more particulate matter when fired by PS 300 or heavier fuel oils than when natural gas or light fuel oils are used.[6]

As expected, centrifugal type water scrubbers were more effective than simple baffled tower water scrubbers. The difference averaged 5.0 lb/hr at constant aggregate fines rate and constant water-gas ratio.

The data, even when corrected for the variables studied, tend to scatter rather badly. However, the results do represent average trends of plants operating in the Los Angeles area. Curves are presented in Fig. 6 and 7 from which the most likely stack emissions can be predicted for oil and gas fired plants with either multiple centrifugal or baffled tower scrubbers. These curves present emissions for various scrubber water-gas ratios and aggregate fines rates.

During the course of conducting several particle size analyses of scrubber inlet and outlet dust, an unusual observation was made. In all of these tests as shown in Table II, the fractional collection efficiency of the 44+ micron material was less than for the 10–20 and the 20–44 micron fractions, which of course is opposite to what would normally be expected. However, microscopic examination of the samples indicated that the particles in the scrubber outlet were agglomerated. Apparently, the fine particles agglomerate within the scrubber, but part of the resulting agglomerates escape to the atmosphere. This potentially recoverable material constitutes five to 10 percent of the scrubber emissions. However, these emissions are minor and even perfect collection of this material would not reduce total emissions over 3.5 lb/hr.

Survey of Dust Emissions in Los Angeles County

In order to evaluate the effect of the control program on dust emissions from the asphaltic concrete industry, it was necessary to acquire information concerning the number of plants in operation, emissions of dust to the atmosphere, amount of asphaltic concrete produced, and volume of air handled.

To obtain the data on production, number of plants, types of controls and operating schedules, a questionnaire was devised and sent to each company operating an asphaltic concrete plant. The data obtained from this survey indicated that in 1957 there were 19 companies

operating 48 plants in Los Angeles County. These plants produced a total of 14,000 tons per day. The data also indicated that asphaltic concrete was produced over a 13-hr day with a maximum hourly output of 1200 tons.

To augment the data obtained from this survey and to make comparisons with data obtained from previous surveys, the analytical test data in the District's files on asphaltic concrete plants were studied. From these studies, average yearly dust emissions to the atmosphere were determined. During the early stages of the development of the control program, many stack tests disclosed emissions of dust in excess of the weight per hour allowed. As the design of control equipment improved, violations became less frequent. During recent years, excessive emissions could be traced to either poor experimental scrubber designs, or more frequently to poor maintenance. It was observed that even well-designed scrubbers would emit excessive dust if a sound maintenance program was not being enforced.

Figure 8 illustrates the effect of the increasing efficiency of the control equipment from 1948 to 1958. Prior to the development of the control program, little or no control devices were installed and an average of five pounds of dust were emitted per ton of asphaltic concrete produced. As the control program progressed and the efficiency of control equipment was increased, dust emissions were reduced until today only 0.15 pound is emitted per ton of asphaltic concrete produced. The major reduction of dust was accomplished between 1948 and 1950. During this period, an average reduction of 150 lb/hr per plant was achieved. From 1950 to the present time, an average reduction of 12 lb/hr per plant has been accomplished due to improvements in controls and better maintenance programs.

The increased efficiency of the control equipment was accomplished even though the average volume of gases handled per plant has increased from 13,000 standard cubic feet per minute in 1951 to 21,000 standard cubic feet per minute in 1958. Figure 9 illustrates this increase in volume. A reduction in volume between 1948 and 1951 is believed to be partially due to conservation of gas volume to allow smaller control devices to be installed. Subsequent to 1951, better control of dust emissions from sources other than the dryer required an increase in gas volume. Moreover, plants have increased in size in recent years.

The data obtained from surveys conducted periodically on the asphaltic concrete industry show that production has increased since 1948 from an average of 10,000 tons per day to more than 14,000 tons per day in 1957 (Fig. 10), an increase of 40 percent. During the same period, dust emissions decreased from 25 tons per day to 1 ton per day, a decrease of 96 per cent overall.

Conclusions

In conclusion, it is emphasized that the variables studied only represent average trends of asphaltic concrete plants in Los Angeles County. With this point in mind, it can be concluded that:

1. Multiple centrifugal scrubbers have proved to be more efficient than baffled towers.

2. Scrubber water-gas ratio is equally important in both types of scrubbers. The best utilization of water is achieved up to a ratio of six gallons per 1,000 standard cubic feet of gas. Above this ratio, efficiency still increases within the bounds studied, but at a lesser rate.

3. Scrubber stack emissions increase linearly with an increase in the amount of minus 200-mesh material charged to the dryer.

4. The burning of PS 300 or heavier fuel oils rather than natural gas results in higher stack emissions. Under constant conditions, an increase of approximately five pounds per hour was observed. Although the available data are not conclusive, it appears that dust emissions are significantly decreased when PS 200 oil is substituted for PS 300 oil.

Through the use of scrubbers, dust emissions from asphaltic concrete plants have been reduced from a total of 25 tons per day to 1 ton per day. If this is related to the increase in production over the 10-year period then the control program is responsible for a net removal of 34 tons per day of dust from the Los Angeles County atmosphere.

REFERENCES

1. Rule 54, Rules and Regulations of the Los Angeles County Air Pollution Control District. In essence, this rule limits the amount of dust and fumes discharged to the atmosphere in any one hour from any source based upon the process weight. For example, if 100 tons per hour of sand and aggregate are charged to the dryer of an asphaltic concrete plant, the process weight is then 200,000 lb/hr. The rule states that for process weights of 60,000 lb/hr or more, the maximum weight of dust and fumes discharged to the atmosphere shall not exceed 40 lb/hr.
2. S. J. Friedman and W. R. Marshall, Jr., "Studies in Rotary Drying," *Chem. Eng. Prog.*, **45**: 8, p. 482 (August, 1949).
3. Los Angeles County Air Pollution Control District, Test Report Series C-426, unpublished reports.
4. R. M. Ingels and G. S. Richards, Los Angeles County Air Pollution Control District, unpublished report.
5. M. Ezekiel, Methods of Correlation Analysis, 2nd Edition, p. 220, John Wiley and Sons, New York (1941).
6. Los Angeles County Air Pollution Control District, Test Report Series C-372, unpublished report.

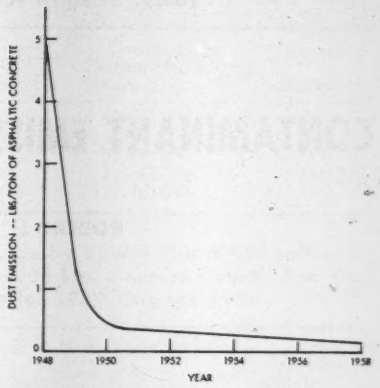

Fig. 8. Reduction of dust emissions from asphaltic concrete plants in Los Angeles County during the period 1948 to 1958.

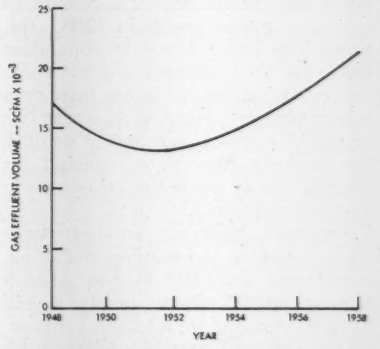

Fig. 9. Asphaltic concrete plant average scrubber effluent volume in Los Angeles County during the period 1948 to 1958.

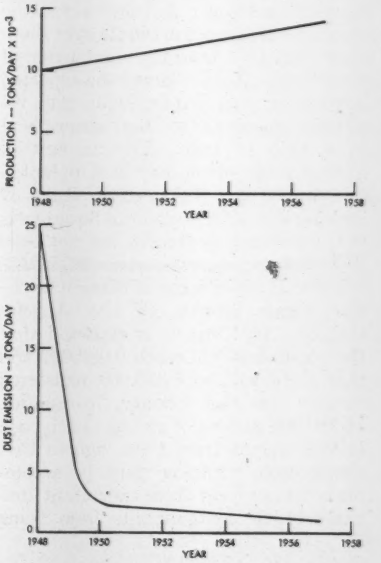

Fig. 10. Average daily production and total dust emissions from asphaltic concrete batching plants in Los Angeles County.

CONTAMINANT EMISSIONS *from the Combustion of Fuels*

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The many attractive features of Southern California living have led to a steady influx of people from other areas. In Los Angeles County, this migration is unprecedented. Since 1940, the population has grown from $2^3/_4$ million to over $5^1/_2$ million people in 1959. Impressive as this increase in population has been, the expansion of commercial and industrial enterprise has been even more dramatic. Keeping pace with this remarkable growth in economic activity has been the growth in demand for thermal energy and in the use of fuels to supply this demand.

By 1980, assuming no restrictions were placed on the burning of fuel oil, community activities in Los Angeles County would require nearly a half million barrels of liquid fuels, exclusive of gasoline, and over $2^1/_2$ billion cubic feet of gaseous fuels daily. The combustion of these fuels would result in the daily emissions to the atmosphere of 2500 tons of sulfur dioxide, 1350 tons of oxides of nitrogen, and 230 tons of combustion contaminants. This would represent a 455 per cent increase in the emissions of air contaminants over those emitted in 1955 from the combustion of these fuels. Table I shows the expected increase in fuel requirements and resulting emissions to the atmosphere from 1955 to 1980. The amount of fuel oil usage which may be supplanted by natural gas because of Rule 62 limiting the sulfur content of liquid fuels to 0.5 per cent by weight, has not been projected in these estimates.

Table II gives some indication of the tremendous growth of Los Angeles County. By 1980, it is expected that the population will reach 9,980,000 and that there will be 6,350,000 registered vehicles in the County, consuming 11,780,000 gallons of gasoline each day. It is apparent from these figures that considerable planning must be accomplished to prevent these exorbitant tonnages of air contaminants from being released into the atmosphere. It is essential that this area be supplied with the cleanest possible fuel—natural gas. As a step to bring this about, the Air Pollution Control Board promulgated, on November 13, 1958, Rule 62 which, in effect, prohibits the use of any liquid fuel containing sulfur compounds in excess of 0.5 per cent by weight during the calendar period of May 1 through October 31. The rule was designed to compel the use of natural gas in Los Angeles County by steam power plants, oil refineries and other industrial and commercial establishments during the summer and early fall months. It is during these periods that meteorological conditions normally are most conducive to the elevation of atmospheric contaminant concentrations.

It has been recognized that weather conditions, favorable to the accumulation of air pollution can also occur during the portions of the year when Rule 62 is not in effect. In order to minimize the emission of contaminants from the combustion of fuel oil on such days, a co-operative voluntary program known as "Operation Fuel Switch" has been entered into by consumers of large quantities of fuel oil.

Operation Fuel Switch was initially instituted at the urging of the Air Pollution Control Officer during the fall of 1957 and continued in an experimental fashion until January 2, 1959. At this time, there was initiated an expanded detailed program involving those consumers who, in the aggregate, account for 80 per cent of the fuel oil used in Los Angeles County.

This program involves the following detailed plan of action:

1. Oil refineries, power plants and other large industrial fuel users voluntarily cease the burning of fuel oil on those days when the APCD requests that Operation Fuel Switch be placed into action because of expected moderate-to-heavy eye irritation.
2. APCD meteorologists notify the local gas co-ordinator of expected smog conditions by means of forecasts issued three times daily—10 A.M. (forecast for the following day), 3 P.M. (forecast for the following day), and 8 A.M. (forecast for the same day).
3. The APCD notifies the oil refineries, power plants and other large industrial fuel users, by means of selective calling facilities, daily at 2 P.M., of the expected air pollution conditions.
4. In the event that the 8 A.M. smog forecast indicates that the two previous forecasts are no longer valid, due to a rapid change in weather conditions, the APCD will inform the local gas co-ordinator, as well as the large users of fuel oil, to that effect at approximately 8 A.M.

It is not within the scope of this paper to present an evaluation of the effects of

Table I—Forecast of Fuel Requirements of Los Angeles County and Resulting Emissions to the Atmosphere

	Fuel Requirements[a]				Emissions to the Atmosphere		
Year	Residual Fuel Oil, Bbls/ Day	Distillate Fuel, Bbls/ Day	Natural Gas, Bbls/ Day[b]	Refinery Gas, Bbls/ Day[b]	Sulfur Dioxide, Tons/ Day	Oxides of Nitrogen, Tons/Day	Combustion Contaminants, Tons/ Day
1955	60,000	5,000	155,000	35,000	420	275	40
1960	80,000	7,000	190,000	45,000	510	360	50
1970	225,000	15,000	285,000	50,000	1,275	750	125
1980	450,000	20,000	380,000	50,000	2,500	1,350	230

[a] R. S. Tulin, Fuel Requirement and Supply—Liquid Petroleum and Natural Gas, District V—Los Angeles Basin, Report of Joint Research Council, Jan. 1958.

[b] Six thousand cubic feet of natural gas or refinery gas is considered equivalent to one barrel of fuel oil.

* Presented at the 52nd Annual Meeting of APCA, June 21–26, 1959, Statler Hotel, Los Angeles, Calif.

Operation Fuel Switch but rather to show that the emission of air contaminants from the burning of fuel oil is one of the three remaining major air pollution problems facing control officials in Los Angeles County. It is hoped that sufficient supplies of natural gas will be made available in the near future to enable Rule 62 to be made applicable the year round. Operation Fuel Switch in the meantime will implement Rule 62 during the so-called winter season.

In view of the enormous tonnages of air contaminants emitted into the atmosphere from the burning of fuel oil, a program was designed to determine emission factors for all types of combustion sources utilizing both liquid and gaseous fuels. This paper presents the results to date of this combustion study.

Consumption of Gaseous and Liquid Fuels in Los Angeles County

The emissions of air contaminants from the burning of fuel oil present a serious air pollution problem in Los Angeles County. Recognition of this fact has created the impetus necessary to acquire the knowledge and understanding of the problem required for its solution. In investigating this problem, an assessment was made of the future demands for thermal energy in view of the vigorous growth in population and industry and the extent to which fuel oil and natural gas respectively had supplied these requirements in the past and would supply them in the future.

Most industrial plants and steam-electric generating power plants in Los Angeles County are equipped to burn both fuel oil and natural gas. Practically all commercial and small industrial establishments, as well as the majority of large industrial establishments, normally burn natural gas with oil used only as a standby fuel. Natural gas is the preferred fuel generally, as it provides thermal energy at the lowest cost per BTU, but the extent to which it is used in lieu of fuel oil is almost entirely dependent upon the availability of natural gas supplies. The majority of large industrial plants receive natural gas on an interruptible basis and, as a result, are not adequately supplied during periods of heavy total demand. Essentially, all of the demand for thermal energy in Los Angeles County is being met with petroleum and natural gas fuels. When gas is not available to meet the demand, the energy deficit is normally filled by residual fuel oil.

Table II—Growth of Los Angeles County

Year	Population	Registered Vehicles	Gasoline Consumption, Gals/Day	Industries
1940	2,785,643	1,220,361	1,920,000	5,900
1950	4,151,687	2,007,552	3,850,000	11,500
1960	6,120,000	3,450,000	6,400,000	17,000
1970	8,050,000	4,900,000	9,100,000	21,000
1980	9,980,000	6,350,000	11,780,000	25,000

Table III—Fuel Oil and Natural Gas Usage by Power Plants, Oil Refineries and Other Interruptible Industrial Sources in Los Angeles County and Gas Supply Potentially Available for 1954 Through 1958

	Expressed as Equivalent Barrels of Fuel Oil[a]			
Year	Fuel Oil Burned	Natural Gas Burned	Natural Gas Available	Natural Gas Available But Not Purchased
1954	15,308,031	25,722,215	29,085,145	3,362,930
1955	20,048,128	24,089,892	24,518,359	428,467
1956	19,665,748	26,362,888	26,575,538	212,650
1957	22,280,017	27,747,525	27,747,525	...
1958	16,562,733	28,082,778	34,481,978	6,399,200

[a] Six thousand cubic feet of natural gas is considered equivalent to one barrel of fuel oil.

In determining the over-all energy requirements of this area and the fuel demand for the future, it was necessary to examine expected population growth and expansion of commercial and industrial activity. Historical data were developed on the demand for liquid and gaseous fuels for the period from 1954 through 1958.

The industrial fuel requirements of this area are met in quite a different manner from that of the rest of the country. Together, oil and natural gas supply essentially 100 per cent of the fuel requirements in Los Angeles County. For the past five years, fuel oil has supplied from 30 to 35 per cent of the area's industrial fuel require-

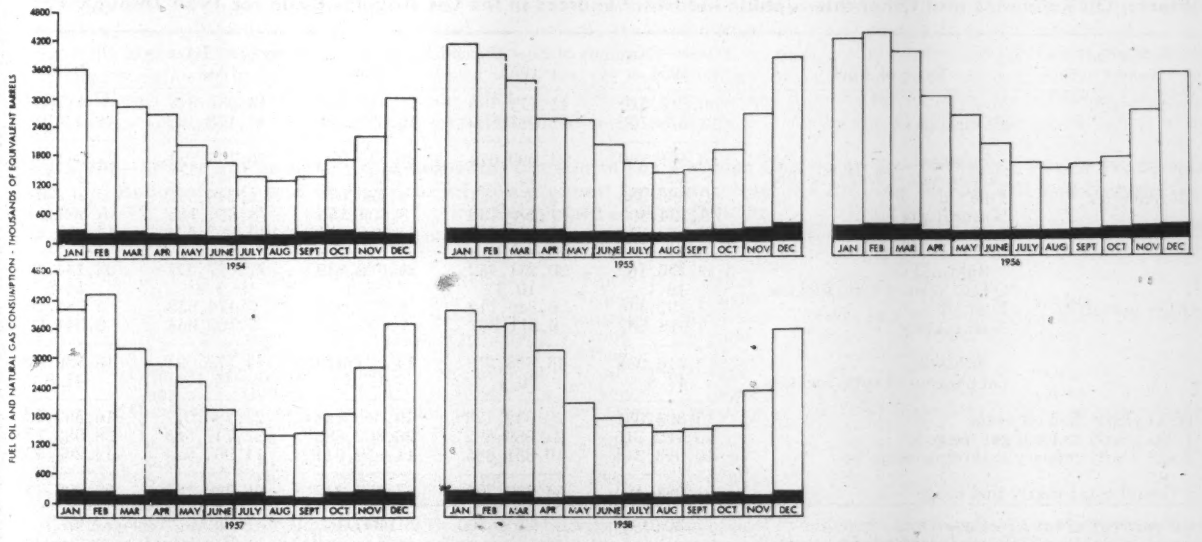

Fig. 1. Five-year summary of monthly fuel oil and natural gas consumption by general service (firm gas) gas customers in Los Angeles County for 1954 through 1958.

Table IV—Five Year Summary of Fuel Oil and Natural Gas Usage and Percentage of Total Fuel Oil and Natural Gas Burned by General Service and Industrial Gas Customers in Los Angeles County for 1954 Through 1958

	Fuel Usage Expressed as Equivalent Barrels of Fuel Oil									General Service		Industrial Sources	
	General Service (Firm Gas Users)[a]			Industrial Sources (Interruptible Gas Users)[b]			Total Fuel Use, All Sources			Oil % of Total Fuel Oil	Gas % of Total Natural Gas	Oil % of Total Fuel Oil	Gas % of Total Natura Gas
Year	Fuel Oil	Natural Gas	Total Fuel Oil	Fuel Oil	Natural Gas	Total Fuel Oil	Fuel Oil	Natural Gas	Grand Total				
1954	2,104,406	24,401,241	26,505,647	15,308,031	25,722,215	41,030,246	17,412,437	50,123,456	67,535,893	12.1	48.7	87.9	51.3
1955	2,639,855	28,246,574	30,886,429	20,048,128	24,089,892	44,138,020	22,687,983	52,336,466	75,024,449	11.6	54.0	88.4	46.0
1956	2,583,207	29,295,600	31,878,807	19,665,748	26,362,888	46,028,636	22,248,955	55,658,488	77,907,443	11.6	52.6	88.4	47.4
1957	2,345,239	29,293,676	31,638,915	22,280,017	27,747,525	50,027,542	24,625,256	57,041,201	81,666,457	9.5	51.4	90.5	48.6
1958	1,904,773	28,671,648	30,576,421	16,562,733	28,082,778	44,645,511	18,467,506	56,754,426	75,221,932	10.3	50.5	89.7	49.5

[a] Includes all domestic, commercial and industrial sources on firm gas schedules.
[b] Includes power plants, oil refineries and all other industrial sources on interruptible gas schedules.

ments, with natural gas and refinery-produced fuel gas supplying the balance.

Data are presented in Tables III through VII and Fig. 1 through 11 on fuel usage by nearly every segment of the domestic, commercial and industrial complex of Los Angeles County. Included in the category of "interruptible industrial sources," are the power plants, oil refineries and other large industrial sources purchasing natural gas on curtailable schedules. The "general service" category includes all domestic, commercial and small industrial users of natural gas, purchasing gas on firm or noncurtailable schedules.

In Table III, historical data are given on the total amount of fuel oil and natural gas consumed by power plants, oil refineries and other large industrial sources in Los Angeles County for the period 1954 through 1958. Also shown are data on the quantities of natural gas which were available to consumers in this area from out-of-state sources, but were not purchased. Fig. 1 through 4 provide a monthly breakdown of oil and natural gas consumption in Los Angeles County for this same five-year period, by general service gas customers, interruptible industrial customers (large industrial sources other than power plants and oil refineries), oil refineries and power plants respectively.

Table IV presents a comparison of fuel usage by general service and industrial gas customers in Los Angeles County for the years 1954 through 1958.

Total yearly fuel usage, as well as a breakdown of the quantities and percentages of each fuel burned by power plants, oil refineries and other interruptible industrial sources in Los Angeles County, is tabulated in Table V.

In Table VI, a monthly breakdown is given of the quantities of fuel oil and natural gas burned in Los Angeles County in 1958 by power plants, oil refineries and other interruptible industrial sources. Also shown is the natural gas supply potentially available for each month of this period and the quantities of natural gas which were available but not purchased during this same period.

Table VII presents an estimate of the total potential fuel requirements of all firm and interruptible gas customers in Los Angeles County (including portions of adjacent counties in the same gas service area) and the potential supply of natural gas projected for the calendar period of May 1–October 31, 1959, through 1965 (effective period of Rule 62).

In projecting the fuel requirements of Los Angeles County no attempt was made to establish how these requirements would be met, except during the period when Rule 62 would be in effect. It is apparent from the forecast of potential fuel requirements that substantial quantities of both fuel oil and natural gas will be needed to meet the estimated demand during the 1959–1970 period. It is expected that the indigenous production of natural gas will not be adequate and gas suppliers will need to rely to an ever increasing degree upon out-of-state supplies.[1] To the increased deliverability already programmed by the natural gas suppliers, even greater expansion will take place within the next ten years. If present contractual agreements of the gas companies for out-of-state gas are approved by all the regulatory bodies, Los Angeles

Table V—Total Yearly Fuel Usage and Percentage of Yearly Fuel Requirements Supplied by Fuel Oil at Power Plants, Oil Refineries and Other Interruptible Industrial Sources in the Los Angeles Basin for 1954 Through 1958

Industrial Source	Type of Fuel	Amount of Fuel Burned Expressed in Equivalent Barrels of Oil[a] 1954	1955	1956	1957	1958
Power plants	Fuel oil	5,012,510	11,111,785	11,417,635	14,557,322	7,414,082
	Natural gas	11,578,750	9,987,889	10,058,395	11,178,402	14,529,994
	Subtotal	16,591,260	21,099,674	21,476,030	25,735,724	21,944,076
	Oil per cent of total fuel use	30.2	52.7	53.2	56.6	33.8
Oil refineries	Fuel Oil	3,098,085	2,089,631	1,420,071	1,248,642	3,362,951
	Natural gas	6,124,863	7,290,136	8,609,156	8,866,155	5,508,158
	Refinery make gas	10,053,214	10,851,685	11,659,611	11,962,624	14,263,276
	Subtotal	19,276,162	20,231,452	21,688,838	22,077,421	23,134,385
	Oil per cent of total fuel use	16.1	10.3	6.5	5.7	14.5
Other industrial	Fuel oil	7,197,436	6,846,712	6,828,042	6,474,053	5,785,700
	Natural gas	8,018,602	6,811,867	7,695,337	7,702,968	8,044,626
	Subtotal	15,216,038	13,658,579	14,523,379	14,177,021	13,830,326
	Oil per cent of total fuel use	47.3	50.1	47.0	45.7	41.8
Total yearly fuel oil usage		15,308,031	20,048,128	19,665,748	22,280,017	16,562,733
Total yearly natural gas usage		25,722,215	24,089,892	26,362,888	27,747,525	28,082,778
Total yearly refinery make gas usage		10,053,214	10,851,685	11,659,611	11,962,624	14,263,276
Grand total yearly fuel usage		51,083,460	54,989,705	57,688,247	61,990,166	58,908,787
Oil per cent of total fuel use		30.0	36.5	34.1	35.9	28.1

[a] Six thousand cubic feet of natural gas is considered equivalent to one barrel of fuel oil.

County will be assured of a natural gas supply sufficient to meet its total potential fuel requirements for the next six years, at least during the six months' period when Rule 62 is in effect.

Emissions from Combustion Sources

Investigations in the control of air pollution from the combustion of fuels was intensified early in 1954 when it was found that in utilizing heavy fuel oils large steam-electric generating installations could not be operated without visible stack emissions or so-called plumes in violation of the Rules and Regulations of the Air Pollution Control District.

A great deal of progress has since been made in the relatively unstudied field of power plant air pollution control through the co-operative efforts of the power generating agencies and the APCD. Research efforts in this direction have been co-ordinated by a Joint Research Council on Power Plant Air Pollution Control, formed in March 1956.

The power plant plume phenomenon is still not fully understood, but it is generally agreed that plume opacity is affected significantly by particulate matter, by the small amount of SO_3 present in the stack effluent, as well as the water vapor present; by ambient atmospheric conditions, by the angle of illumination, and by the kind of background against which the plume is observed.[2]

From the available stack test data on power plants, an evaluation was made of the contribution of this source to air pollution. Table VIII shows the effects of population and industrial growth in Los Angeles County on steam-electric power production projected to 1970. Also shown are the fuel requirements and a comparison of contaminant emissions from the burning of fuel oil and the natural gas equivalent of fuel oil.

In 1959, the total annual power requirement is estimated at 24 billion kilowatts. Of this total, approximately 15 to 16 billion kilowatts, or 65 per cent, will be supplied by steam generating power plants within the County. If all of these plants were to burn fuel oil exclusively with an average sulfur content of 1.5 per cent, the resultant emissions would be 320 tons per day of sulfur dioxide, 185 tons of oxides of nitrogen and 30 tons of combustion contaminants. If natural gas were burned exclusively, such emissions would be reduced to 0.1 ton per day of sulfur dioxide, 120 tons of oxides of nitrogen and 3 tons of combustion contaminants.

Table VI—Fuel Oil and Natural Gas Burned in Los Angeles County in 1958 by Power Plants, Oil Refineries and Other Interruptible Industrial Sources and Natural Gas Supply Potentially Available

Month	Expressed as Equivalent Barrels of Fuel Oil[a]			
	Fuel Oil Burned	Natural Gas Burned	Natural Gas Available	Natural Gas Available But Not Purchased[b]
Jan.	1,753,633	2,009,795	2,030,212	20,417
Feb.	1,254,064	2,358,481	2,383,881	25,400
Mar.	1,501,254	2,014,588	2,015,671	1,083
Apr.	1,202,338	1,886,987	2,516,487	629,500
May	955,591	2,447,140	3,214,640	767,500
Jun.	1,110,967	2,572,725	3,429,492	856,767
Jul.	1,204,291	2,459,144	3,468,544	1,009,400
Aug.	1,490,374	2,517,193	3,637,443	1,120,250
Sep.	1,265,994	2,755,359	3,557,542	802,183
Oct.	1,309,164	2,672,581	3,389,848	717,267
Nov.	1,745,366	2,103,385	2,435,118	331,733
Dec.	1,769,697	2,285,400	2,403,100	117,700
Totals	16,562,733	28,082,778	34,481,978	6,399,200

[a] Six thousand cubic feet of natural gas is considered equivalent to one barrel of fuel oil.
[b] Estimated out-of-state supply.

Table VII—Potential Fuel Requirements of All Firm and Interruptible Gas Customers and Potential Supply of Natural Gas Projected for the Calendar Period May 1– October 31, 1959, Through 1965[a]

Year	Millions of Cubic Feet Per Day		
	Potential Requirements[b]	Potential Supply	Expected Surplus
1959	1,680.6	1,680.6	0
1960	1,927.6	2,086.3	158.7
1961	2,017.5	2,178.7	161.2
1962	2,118.2	2,275.4	157.2
1963	2,185.0	2,272.6	87.6
1964	2,303.0	2,400.1	97.1
1965	2,443.1	2,482.3	39.2

[a] Forecast estimates by Pacific Lighting Gas Supply Company.
[b] Refinery make gas not included.

Although the oil refineries in Los Angeles County burn only a third as much fuel oil as the power plants, their combined fuel usage, including refinery make gas, is greater than the total fuel usage by power plants. In August 1955, a study was initiated to determine the extent of the emissions from combustion sources in oil refineries.[3]

The total annual consumption of fuel oil, natural gas and refinery make gas by the oil refineries in 1958 amounted to over 23 million equivalent barrels or an

Table VIII—Effects of Population and Industrial Growth in Los Angeles County on Steam-Electric Power Production and Fuel Requirements and Comparison of Contaminant Emissions from the Burning of Fuel Oil and Natural Gas Equivalent of Fuel Oil[a]

Year	Population (Millions)	Total Power Requirement (Billion Kilowatt-Hours per Year)	Steam-Electric Power Production (Billion Kilowatt-Hours per Year)	Fuel Required for Power Production (Thousand Equivalent Barrels per Day)	Sulfur Dioxide Emissions from Fuel Oil (Tons per Day)	Sulfur Dioxide Emissions from Natural Gas (Tons per Day)	Nitrogen Oxide Emissions from Fuel Oil (Tons per Day)	Nitrogen Oxide Emissions from Natural Gas (Tons per Day)	Aerosol Emissions from Fuel Oil (Tons per Day)	Aerosol Emissions from Natural Gas (Tons per Day)
1950	4.2	8	4.5	20	105	0.02	60	40	10	1
1958	5.6	24	15	60	320	0.1	185	120	30	3
1970	8	66	43	190	1020	0.2	570	380	95	10

[a] Los Angeles County Air Pollution Control District Fuel Survey; R. S. Tulin, Fuel Requirement and Supply—Liquid Petroleum and Natural Gas, District V—Los Angeles Basin; Twenty-Eighth Annual Report—Utilities—Los Angeles Area, 1957–1958 Los Angeles Chamber of Commerce.

Table IX—Description of Equipment Tested

Reference No.	Equipment	Type	Burner Data — Gas — Mfg.	Gas — Type	Gas — Pressure, Psig	Oil — Mfg.	Oil — Type	Oil — Pressure, Psig	Oil — Temp., °F	Draft	Combustion Controls — Gas	Combustion Controls — Oil	Steam Pressure, Psig	Fuels Burned — Gas	Fuels Burned — Oil	Test No.
1	Thompson Tubeless Boiler—30 hp	Tubeless	Thompson	Premix Aspirator	0.3	—	—	—	—	Natural	Automatic	—	15	Natural	—	C-526
2	Cyclotherm Steam Generator—60 hp	Fire-Tube	Cyclotherm	Nozzle Mix	0.3	Cyclotherm	Pressure Atomizing	150	70	Natural	Automatic	Automatic	70	Natural	PS200	C-494
3	Bryan No. 315—100 hp	Water Tube	—	—	—	Johnson BH-2A	Pressure Atomizing	115	70	Natural	—	Automatic	Hot Water	—	PS200	C-509
4	Locomotive Type Boiler—120 hp	Single-Pass Fire-Tube	—	—	—	N.A.	Steam Atomizing	N.A.	160	Natural	—	Manual	100	—	PS300	C-456
5	Pioneer Boiler—125 hp	Scotch Marine	—	—	—	N.A.	Pressure Atomizing	52	70	Natural	—	Automatic Off-On	90	—	PS300	C-493
6	Dixon Water Wall Boiler—125 hp	Scotch Marine	Nemec	Multi-Jet Ring Type	0.3	—	—	—	—	Natural	Automatic Modulating	—	100	Natural	—	C-451
7	Dixon Water Wall Boiler—150 hp	Scotch Marine	Nemec	Multi-Jet Ring Type	0.3	Nemec	Steam Atomizing	N.A.	70	Natural	Automatic Modulating	Semi-Automatic	100	Natural	PS200	C-450
8	Gabriel Boiler—150 hp	Scotch Marine	Johnson 150	Multi-Jet Ring Type	0.3	Johnson 150	Centrifugal Atomizing	140	70	Natural	Automatic Modulating	Automatic Off-On	10	Natural	Diesel	C-454
9	Johnston Boiler No. 18—200 hp	Scotch Marine	Johnston	Multi-Jet Ring Type	0.3	Johnston Rotary	Centrifugal Atomizing	N.A.	70	Natural	Automatic	Automatic	90	Natural	Diesel	C-455
10	B & W Boiler Model FM-27—200 hp	Water-Tube	Todd	Multi-Jet Ring Type	0.3	Todd	Pressure Atomizing	25	70	Natural	Automatic	Automatic	120	Natural	Diesel	C-527
11	Erie City Boiler Model 4C-14—245 hp	Water-Tube 3-Drum	Leahy	MCL 7-23 4-Segment	9	Leahy	MCL 7-23	85	205	Induced	Automatic Modulating	Semi-Automatic	120	Natural	PS400	C-596
12	B & W Boiler Type FM-1—300 hp	Water-Tube	Todd Roto-Press	Ring Type	3.5	Todd Roto-Press	Centrifugal Atomizing	7.5	70	Natural	Automatic	Automatic	600	Natural	PS200	C-595
13	Kewanee Boiler Model 590—300 hp	Modified HRT 2 Pass-Fire-Tube	Martois	A-27-6 Multi-Jet	3.5	Leahy	Steam Atomizing	100	60	Induced	Automatic Modulating	Semi-Automatic	100	Natural	PS200	C-591
14	Dixon Wet Back Boiler—350 hp	Scotch Marine	Enterprise	Multi-Jet Ring Type	0.3	Enterprise	Centrifugal Atomizing	N.A.	70	Induced	Automatic Modulating	Automatic Modulating	150	Natural	Diesel	C-525
15	Collins Boiler—425 hp	Water-Tube	Lientz No. 611-A	Multi-Jet Nozzle Mix	0.5	Lientz No. 611-A	Steam Atomizing	40	210	Natural	Automatic	Automatic	160	Natural	PS400	C-452
16	Springfield Boiler—460 hp	Water-Tube	Peabody	Multi-Jet Ring Type	3.0	Peabody	Pressure Atomizing	200	170	Induced	Automatic Modulating	Automatic Modulating	275	Natural	PS300	C-593
17	Sterling Boiler Model 477-31 (Modified)—500 hp	Water-Tube 4-Drum	Nemec	Multi-Jet Nozzle Mix	7.0	Nemec	Steam Atomizing	65	160	Induced	Automatic Modulating	Semi-Automatic	145	Natural	PS300	C-592
18	Collins Boiler—580 hp	Water-Tube	Nemec	Multi-Jet Ring Type	0.3	Nemec	Steam Atomizing	45	160	Natural	Automatic	Automatic	15	Natural	PS300	C-443
19	B & W Boiler Model FM-9—870 hp	Water-Tube	B & W	Multi-Jet Ring Type	2.3	B & W Y-Jet	Steam Atomizing	58	220	Natural	Automatic	Automatic Modulating	275	Natural	PS400	C-459
20	General Water Heater Corp. Model A-75 H	75 Gallon Hot Water Heater	General	Premix Multi-Jet	0.3	—	—	—	—	Natural	Automatic Off-On	—	—	Natural	—	C-446
21	Utility Appliance Corp. Model 125 UF Space Heater	100,000 Btu/hr. Forced Air Heater	Utility	Premix Inspirator	0.3	—	—	—	—	Natural	Automatic Off-On	—	—	Natural	—	C-447
22	Vensel Bonderizing Oven	Indirect Fired	N.G.E.	3″ Premix Aspirator	0.3	—	—	—	—	Natural	Semi-Automatic	—	—	Natural	—	C-507
23	Vensel Paint Bake Oven	Indirect Fired	Eclipse	2½″-#1462 Premix Aspirator	0.3	—	—	—	—	Natural	Automatic Off-On	—	—	Natural	—	C-506
24	Bake Oven	Indirect Fired	Pacific Gas	Premix Inspirator	0.3	—	—	—	—	Natural	Manual	—	—	Natural	—	C-508
25	425 Pound Crucible Type Aluminum Melting Furnace	Indirect Fired	Custom Made	Premix Aspirator	0.3	—	—	—	—	Natural	Manual	—	—	Natural	—	C-505
26	Childers Oil Heater Model D-100	Oil Circulating Heat Exchanger	—	—	—	Childers	Pressure Atomizing	N.A.	70	Natural	—	Automatic Off-On	—	—	PS200	C-457
27	Prouty Custom Artware Kiln	Indirect Fired Full Muffle	Petro-Fire	Premix Aspirator	0.3	Petro-Fire	Premix Vaporizer	0.5	70	Induced	Automatic Modulating	Automatic Modulating	—	Natural	PS100	C-502
28	Lehr Glassware Decorating Oven	Indirect Fired Full Muffle	Custom Made	Premix Inspirator	1.0	—	—	—	—	Natural	Automatic Modulating	—	—	Natural	—	C-465
29	Ceramic Tunnel Kiln	Indirect Fired	Custom Made	Premix Inspirator	—	—	—	—	—	Natural	Automatic Modulating	—	—	Natural	—	C-463
30	Semi-Muffle Dinnerware Kiln	Indirect Fired	Petro-Fire	Premix Inspirator	0.5	Petro-Fire	Premix Vaporizer	0.5	—	Induced	Automatic	Automatic	—	Natural	Kerosene	C-504

— Does not apply.
N.A.—Not Available.

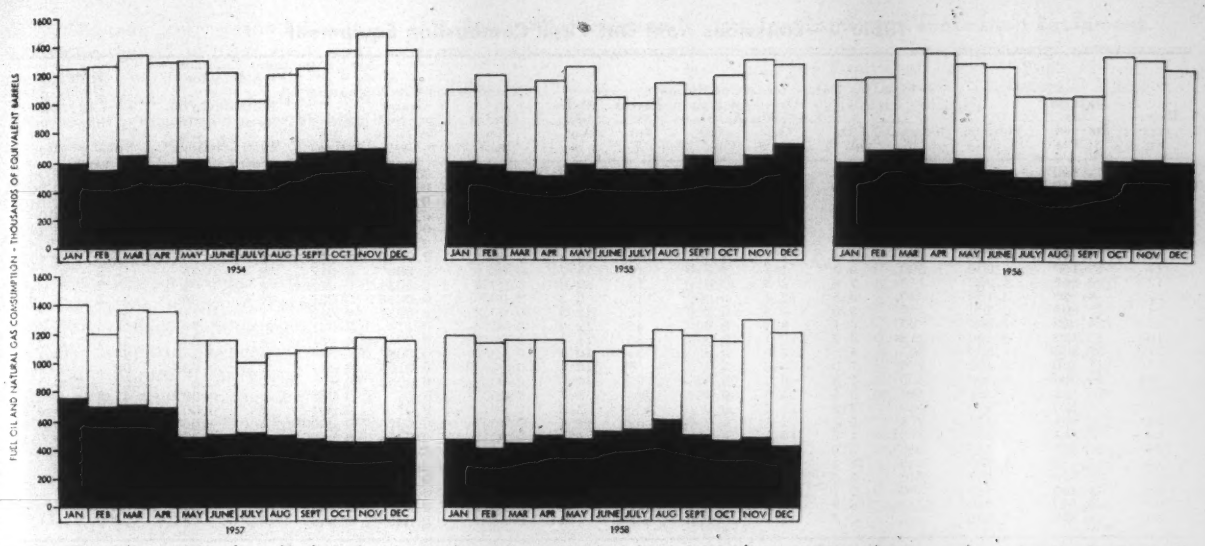

Fig. 2. Five-year summary of monthly fuel oil and natural gas consumption by other industrial (interruptible gas) gas customers in Los Angeles County for 1954 through 1958.

annual daily average fuel usage of over 63 thousand equivalent barrels. The combustion of these fuels by refineries resulted in daily emissions to the atmosphere of 115 tons of sulfur dioxide, 50 tons of nitrogen oxides and 10 tons of combustion contaminants.

APCD Stack Testing Program

The total fuel usage by other interruptible industrial sources approximates only 20 per cent of the combined fuel usage by power plants and oil refineries, but in the consumption of fuel oil it is the second largest source. In view of this, and in the absence of sufficient data to allow an evaluation of the emissions from this category of industrial combustion sources, an investigation and tack testing program was initiated sarly in 1957. Preliminary planning required the identification of all commercial and industrial processes or operations utilizing combustion equipment. It was necessary also to predetermine that, in a stack test of the equipment selected, it would be possible to sample only the contaminants resulting from the combustion of fuels and to exclude the emissions from any other portion of the integrated process. In selecting the equipment for testing, an attempt was made to include as many different types and sizes of equipment as possible. Aside from these considerations, the units selected for testing were based on accessibility and availability of adequate sampling facilities. Included in addition to the obvious sources, i.e., boilers and heaters, such equipment as driers, ovens and furnaces operating on both oil and gas were tested. Of the 30 units of combustion equipment listed in Table IX, 15 were tested while fired with both gas and oil fuels. Eleven were tested on natural gas firing only, and four were tested on oil firing only, giving a total of 45 stack tests. Over 800 separate analyses were required to determine the emissions of contaminants from the combustion sources tested.

All of the stacks were tested for combustion contaminants,* aldehydes, oxides of nitrogen, sulfur dioxide, sulfur trioxide, hydrocarbons, carbon monox-

* "Combustion Contaminants" are particulate matter discharged into the atmosphere from the burning of any kind of material containing carbon in a free or combined state. (Rule 2m of the Los Angeles County Air Pollution Control District Rules and Regulations.)

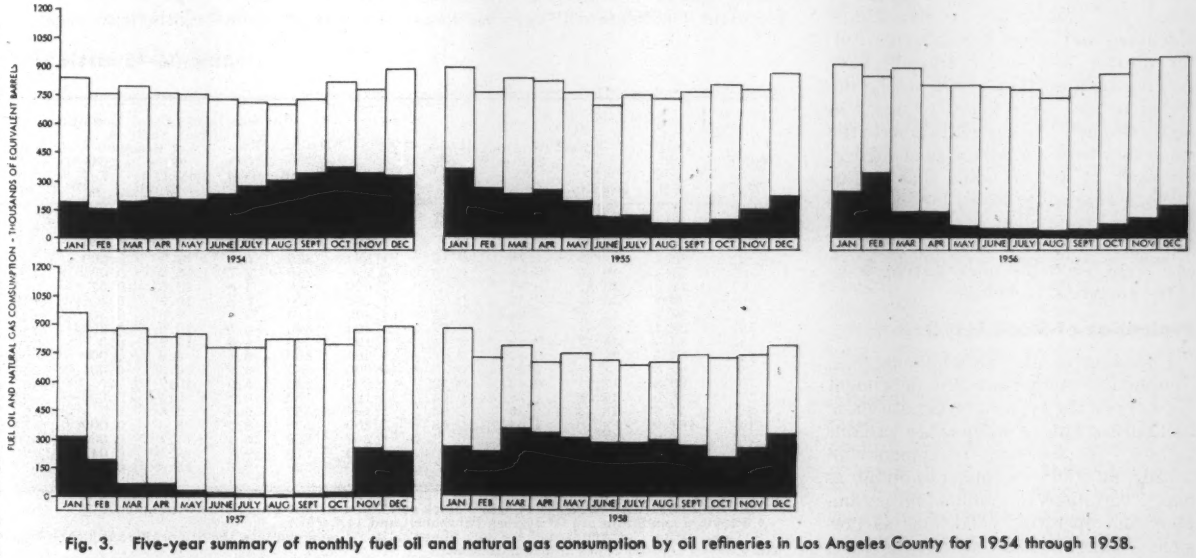

Fig. 3. Five-year summary of monthly fuel oil and natural gas consumption by oil refineries in Los Angeles County for 1954 through 1958.

Table X—Emissions from Gas Fired Combustion Equipment

Reference No.	Natural Gas Burned, SCFH	Flue Gas Data—Stack Conditions: Volume, SCFM[b]	Temp., °F	CO_2, Vol. %	Orsat Analysis (Wet Basis): O_2, Vol. %	CO, Vol. %[c]	Excess Air, Vol. %	Moisture, Vol. %	Air Contaminant Emissions[a]: Combustion Contaminants[d] Grains per SCF	Grains per SCF @ 12% CO_2	Pounds per Hour	Aldehydes (as Formaldehyde) Ppm	Pounds per Hour	Oxides of Nitrogen (As NO_2) Ppm	Pounds per Hour
1	840	400	550	4.8	10.0	0.000	98	9.2	0.0035	0.0088	0.012	3	0.005	33	0.10
2	2,040	720	300	4.5	9.3	0.1	93	14.3	0.019	0.051	0.12	4	0.02	37	0.20
6	6,600	1,200	460	4.2	1.7	6.4	0	15.6	0.035	0.10	0.36	25	0.1	5	0.04
7	7,200	1,800	580	7.4	2.3	0.2	13	18.3	0.0049	0.0079	0.08	2	0.02	28	0.4
8	2,220	2,700	160	1.7	17.2	0.00	28	4.3	0.0004	0.003	0.009	3	0.05	8	0.16
9	4,260	1,700	370	4.8	9.6	0.000	94	10.8	0.0011	0.0028	0.016	4	0.03	13	0.16
10	2,487	1,250	380	3.8	11.3	0.000	135	10.8	0.0017	0.0054	0.018	11	0.065	16.1	0.146
11	14,100	5,000	500	5.4	2.7	4.6	16	14.7	0.0018	0.004	0.077	19	0.45	12.8	0.47
12	4,860	1,200	440	7.8	2.3	0.01	13	16.6	0.0022	0.0034	0.02	3	0.02	38.2	0.334
13	6,120	3,100	330	3.8	12.4	0.000	124	8.2	0.0079	0.0025	0.021	4	0.06	34.8	0.79
14	10,800	4,100	480	5.0	8.2	0.000	72	13.3	0.0013	0.0031	0.046	7	0.14	56	1.7
15	24,600	7,800	600	6.1	6.4	0.02	48	12.9	0.0576	0.113	3.8	53	1.7	111.6	5.50
16	15,420	5,400	218	5.2	9.1	0.0	85	11.2	0.0018	0.004	0.08	4	0.09	39.4	1.55
17	28,800	11,500	600	4.8	9.0	0.0	84	10.9	0.0033	0.0082	0.33	4	0.2	124	10.4
18	11,100	2,400	470	7.0	0.5	1.8	0	18.0	0.00619	0.0106	0.13	3.5	0.033	92	1.3
19	24,000	9,200	480	5.0	8.1	0.02	73	14.6	0.0022	0.0053	0.17	10	0.5	127	8.5
20	117	81	110	3.4	14.6	0.001	203	5.7	0.007	0.03	0.005	2	0.002	45.8	0.026
21	130	124	160	2.0	17.7	0.0	480	3.8	0.001	0.01	0.001	2	0.001	19.0	0.016
22	408	155	373	5.0	9.5	0.000	99	11.6	0.0007	0.002	0.0009	3	0.003	34.1	0.038
23	384	230	370	1.7	16.6	0.000	437	5.0	0.0013	0.009	0.0026	6	0.006	16.0	0.026
24	582	310	250	3.5	14.7	0.000	38	7.0	0.0018	0.062	0.0048	6	0.008	19.5	0.045
25	1,146	1,300	330	18.1	1.0	0.000	6	20.0	0.0069	0.075	0.073	0	0	102	0.16
27	619	240	440	5.6	9.1	0.04	67	5.6	0.002	0.01	0.004	2.2	0.0025	13.4	0.023
28	420	422	360	0.7	19.4	0.0	[e]	2.9	0.0012	0.021	0.0043	3.9	0.0045	2.8	0.0046
29	1,140	450	1040	4.9	10.0	0.000	105	11.7	0.0021	0.0051	0.0081	5	0.01	66	0.22
30	4,679	1,100	590	2.7	15.7	0.000	355	6.1	0.0051	0.023	0.048	6.7	0.035	18.8	0.15

[a] All concentrations expressed at actual stack conditions except where otherwise noted.
[b] Standard conditions are 60 degrees Fahrenheit and 14.7 PSIA.
[c] All CO measurements below 0.1% were made with M.S.A. instrument.
[d] "Combustion Contaminants" are particulate matter discharged into the atmosphere from the burning of any kind of material containing carbon in a free or combined state. (Rule 2m of the Los Angeles County Air Pollution Control District Rules and Regulations.)
[e] Excess air introduced after combustion zone.

ide, carbon dioxide and oxygen. In the majority of tests the stack gas flow rate was determined directly by Pitot traverse, but where physical limitations or location of the sampling stations did not allow a direct measurement, the flow rate was calculated using stoichiometric principles. The temperature of the stack gases was measured in all cases. Fuel rate and fuel composition were also obtained. In the case of natural gas-fired equipment, the gas composition was assumed as 85 per cent methane, 12 per cent ethane and three per cent inert material, which is the average composition of natural gas burned in this area.

The results of the source testing program are shown in Tables X and XI. It will be noted in Table X, which gives the emissions from gas-fired combustion equipment, that the only contaminants listed are combustion contaminants, aldehydes and oxides of nitrogen. Sulfur dioxide and sulfur trioxide were omitted because they could not be detected or else were found to occur in such extremely low concentrations in the stack they were considered as negligible. Similarly, it will be noted that hydrocarbons were not reported for either gas or oil-fired equipment as the concentrations in which they occurred in every case were below the quantitative range of the analytical technique.

Evaluation of Stack Test Data

Emissions of air contaminants from combustion equipment are dependent not only on the type and composition of fuel burned but on many other variable factors. In selecting equipment for testing, an effort was made to obtain as many variations of combustion parameters and operating conditions as possible. This was done so that the stack test data would reflect an average or representative cross section of industrial combustion sources.

In Tables XII and XIII are shown the emission factors for the combustion sources tested. Emission factors for each of the contaminants were calculated from the test data for both oil-fired and gas-fired equipment in terms of pounds per equivalent barrel of fuel oil.

Emissions of sulfur oxides are a direct function of the fuel composition, while the emissions of other contaminants are influenced by such variables as combustion chamber design, method of combustion-air introduction, combustion temperature, burner design, burner spacing or configuration and other combustion parameters. From the test data obtained, no correlation can yet be found to show the extent to which contaminant emissions will vary as combustion parameters differ. Contrary to popular opinion, the emissions of air contaminants will vary considerably from similar types of equipment and from similar sizes of the same equipment.

The measured values of sulfur dioxide agreed quite well with the values calculated from the fuel analysis. In the oil-fired combustion equipment, nitrogen oxide concentrations varied from a low of 14.7 to a high of 387 parts per million. The results obtained for gas operation varied from a low of 2.8 to a high of 127 parts per million. As expected, the nitrogen oxide concentrations for any given unit of combustion equipment tested were found to be lower when the equipment was fired with natural gas than when fired with fuel oil.

Studies made by other investigators[5]

Table XI—Emissions from C

Reference No.	Fuel Oil Burned, GPH	Fuel Oil Analysis: API Gravity	Sulfur, Wt. %	Ash, Wt. %	Flue Gas Data—Stack Conditions: Volume, SCFM[b]	Temp., °F	Orsat Analysis (Wet Basis): CO_2, Vol. %	O_2, Vol. %	CO, Vol. %	Excess Air, Vol. %	M
2	9	31.07	1.05	0.02	390	250	7.0	7.9	0.01	65	
3	6.1	28.71	0.71	0	510	290	3.9	15.2	0.000	290	
4	36.3	16.51	1.0	0	1,800	710	7.0	7.8	0.003	68	
5	23.1	11.39	1.78	0.18	1,800	330	5.0	13.3	0.000	180	
8	15.3	40.10	0.09	0	1,700	240	2.7	16.2	0.001	150	
9	21.0	33.82	0.97	0	2,000	360	4.3	13.8	0.02	210	
10	9.7	35.09	0.55	0	1,290	370	2.8	16.3	0.002	370	
11	99.4	11.10	0.94	0.13	4,300	540	7.9	6.0	0.00	43	
12	23.1	33.01	0.21	0.07	1,300	390	5.5	10.9	0.0024	115	
13	39.6	34.87	0.29	0.01	3,100	320	4.0	13.9	0.0	220	
14	85.5	32.9	0.42	0	4,200	500	6.3	9.8	0.000	94	
15	160.0	8.0	3.06	0	10,600	630	6.3	10.3	0.001	110	
16	80.5	12.11	0.78	0.12	4,800	220	5.9	10.7	0.0	107	
17	248.0	15.09	1.39	0.04	13,100	560	6.7	9.5	0.000	92	
18	57.5	13.33	1.30	0.03	3,200	580	6.4	9.6	0.0	95	
19	168.0	9.30	1.94	0.03	7,800	530	8.2	8.5	0.000	73	
26	5.2	33.6	0.80	0	290	820	5.4	11.1	0.002	120	
27	10.0	45.1	Trace	0	230	410	9.7	3.5	0.04	21	
30	20.0	45.1	Trace	0	1,200	520	3.0	15.9	0.000	373	

[a] All concentrations expressed at actual stack conditions except where otherwise noted.
[b] Standard conditions are 60 degrees Fahrenheit and 14.7 PSIA.
[c] "Combustion Contaminants" are particulate matter discharged into the atmosphere from the burning of
tion Control District Rules and Regulations.)

on 22 different power plant boiler installations showed nitrogen oxide concentrations varying from 330 to 915 parts per million on fuel oil firing and 160 to 1350 ppm on gas firing. Nitrogen oxide results obtained on a coal-fired power plant boiler varied from a low of 650 to a high of 1460 ppm.

Estimates of the emissions of air contaminants from the combustion of fuels by industrial sources were obtained by using an average of the emission rate factors shown in Tables XII and XIII. Information on the number of each of the various types and sizes of combustion sources operating within Los Angeles County was inadequate to allow the emission rate factors to be weighted; however, the total contaminant emission estimates obtained by using average values are believed to be sufficiently accurate.

The total annual consumption of fuel oil and natural gas by interruptible industrial sources, other than power plants and oil refineries, amounts to nearly 14 million barrels, giving an annual daily average fuel usage of approximately 38,000 equivalent barrels. The combustion of these fuels results in emissions to the atmosphere daily of approximately 65 tons of sulfur dioxide, 30 tons of nitrogen oxides and 10 tons of combustion contaminants.

Approaches to Control

There are presently within the boundaries of Los Angeles County an estimated 15,000 industrial establishments, 11 steam-electric generating power plants, seven major and nine minor oil refineries. These industrial units collectively consume an average of over 50,000 barrels of fuel oil each day. During periods of peak fuel use, the consumption of fuel oil has been as much as 100,000 barrels per day. The burning of fuel oil in these quantities results in emissions to the atmosphere of from 400 to nearly 800 tons per day of various air contaminants.

Table XII—Emission Factors for Gas Fired Combustion Equipment

Reference No.[a]	Pounds per Equivalent Barrel of Fuel Oil[b] — Combustion Contaminants	Aldehydes (as Formaldehyde)	Oxides of Nitrogen (as NO_2)
1	0.086	0.036	0.714
2	0.353	0.059	0.588
6	0.327	0.091	0.036
7	0.067	0.017	0.333
8	0.024	0.135	0.432
9	0.023	0.042	0.225
10	0.043	0.157	0.352
11	0.033	0.191	0.200
12	0.025	0.025	0.412
13	0.021	0.059	0.774
14	0.026	0.078	0.944
15	0.927	0.415	1.341
16	0.031	0.035	0.603
17	0.069	0.042	2.167
18	0.070	0.018	0.703
19	0.042	0.125	2.125
20	0.256	0.070	1.333
21	0.046	0.046	0.738
22	0.013	0.044	0.559
23	0.041	0.094	0.406
24	0.049	0.082	0.464
25	0.382	0	0.838
27	0.038	0.024	0.223
28	0.061	0.064	0.066
29	0.043	0.053	1.158
30	0.062	0.045	0.192

[a] Numbers refer to equipment listed in Table IX.
[b] Six thousand cubic feet of natural gas is considered equivalent to one barrel of fuel oil.

In Table XIV data are presented on the estimated daily emissions of sulfur dioxide, oxides of nitrogen and aerosols from the combustion of liquid and gaseous fuels and from other air pollution sources in Los Angeles County. It may be seen from these data that an average of 310 tons per day, or 68 per cent, of the total emissions of sulfur dioxide in Los Angeles County are from the combustion of fuels. It will also be noted that 250 tons per day of nitrogen oxides, or 36.1 per cent, are emitted from combustion sources. The combustion of fuels also releases 35 tons per day, or 40 per cent, of the total emissions of aerosols from both stationary and vehicular sources.

For purposes of comparison there are shown in Fig. 5 the relative amounts of combustion contaminants, nitrogen oxides and sulfur dioxide emitted from the burning of fuel oil and from the burning of an equivalent amount of natural gas. The annual daily average fuel consumption by interruptible industrial sources was used for this comparison. It can be seen that, if the average daily fuel requirements of all industrial sources amounting to over 120,000 barrels were supplied with fuel oil, there would be released to the atmosphere daily 600 tons of sulfur dioxide, 270 tons of nitrogen oxides and 50 tons of combustion contaminants. Were these same fuel requirements supplied by natural gas, there would be emitted a negligible amount of sulfur dioxide, 150 tons of nitrogen oxides and only five tons per day of combustion contaminants.

The largest single industrial users of both fuel oil and natural gas in Los Angeles County are the steam-electric generating power plants. In burning residual fuel oils the power plants cannot be operated so as to comply with the Rules and Regulations governing visible emissions and nuisances. Visible stack emissions, or so-called plumes, from power plant stacks are the result of the daily burning of thousands of tons of fuel oil. Depending upon weather conditions, these effluent stack plumes may extend for several miles, carrying pollution over a widespread area, or they may cause heavy concentrations of pollution at ground level adjacent to these plants. This latter effect has frequently been encountered in areas surrounding power plants and oil refineries, where heavy local concentrations have caused paint damage, damage to vegetation and troublesome soot problems.

red Combustion Equipment

Combustion Contaminants[c] Grains per SCF	Grains per SCF @ 12% CO_2	Air Contaminant Emissions[a] — Sulfur Dioxide Pounds per Hour	Ppm	Sulfur Trioxide Pounds per Hour	Ppm	Aldehydes (as Formaldehyde) Pounds per Hour	Ppm	Oxides of Nitrogen (as NO_2) Pounds per Hour
.041	0.069	0.14	355	1.4	1.6	0.0080	9	0.017	47	0.13
.023	0.071	0.10	98.2	0.51	1.4	0.0092	5	0.013	35.8	0.13
.043	0.074	0.66	414	7.5	4.7	0.10	7	0.05	368	4.8
.0439	0.11	0.68	264	5.0	3.2	0.076	9	0.08	128	1.68
.0085	0.038	0.12	28	0.48	1.7	0.036	5	0.04	20	0.25
.0498	0.14	0.85	11.2	2.3	5.6	0.00006	52	0.50	21	0.31
.023	0.10	0.26	0.2	0.0024	0	0	8	0.04	54.9	0.51
.042	0.064	1.55	397	17.3	0.37	0.020	8	0.2	387	12+1
.020	0.041	0.22	102	1.35	0.5	0.008	7	0.04	32.8	0.310
.0472	0.142	1.25	7.1	2.24	0.0	0.0	6	0.08	14.7	0.33
.0072	0.014	0.26	17	7.2	0	0	3	0.06	72	2.2
.147	0.28	13.4	700	75	6.7	1.2	4	0.2	274.9	19.8
.0193	0.039	0.79	362	17.6	2.2	0.13	7	0.2	199	6.95
.0249	0.0446	2.80	594	79.0	3.6	0.6	17	1.0	256	24.5
.032	0.060	0.87	640	21	2.2	0.091	8.5	0.12	205.9	4.3
.0653	0.096	4.4	344	27.2	1.2	1.2	48	1.8	256	14.6
.033	0.073	0.081	138	0.41	2.8	0.003	11	0.015	33.7	0.065
.001	0.004	0.002	0	0	0	0	3.5	0.0037	27.1	0.045
.094	0.038	0.097	0.17	0.0021	0	0	3.4	0.020	19.8	0.17

d of material containing carbon in a free or combined state. (Rule 2m of the Los Angeles County Air Pollu-

The direct control of power plant emissions in Los Angeles County has been approached from three aspects: (1) treatment of the fuel; (2) boiler modification; and (3) treatment of the effluent. At the present time, there is no steam-electric generating power plant in the world known to have control equipment which is entirely satisfactory for removing any one of the contaminants produced from the burning of fuel oil. Furthermore, no practical means have as yet been devised for removing, before burning, the objectionable elements such as sulfur and other inorganic materials present in the fuel oil which give rise to these air contaminants.

Alternative Fuels and Treatment of Fuels

The importation of low sulfur content fuel oils has been proposed as an alternative to the presently used fuels. Studies have shown that the possibility of obtaining fuel oils of low sulfur and low ash contents from other major refinery areas is remote, even at premium prices.

Investigations have shown that no commercially feasible process is yet available for removal of sulfur or other inorganic materials from residual fuel oil which are responsible for the sulfur and metal oxides in the boiler effluent. Since there is no correlation of oxides of nitrogen in the boiler effluent with the concentration of nitrogen compounds in the fuel oil, a significant reduction would not result from the removal of nitrogen containing compounds in the fuel oil.

Changes in Boiler Design or Operation

Boiler design or operational changes will not effect a significant reduction in the amount of sulfur oxides emitted to the atmosphere from an oil-fired boiler, since this is a function of fuel composition. Recent investigations have demonstrated that the main factors affecting nitrogen oxide formation are furnace design and several combustion parameters. It may be possible to so modify boiler designs that nitrogen oxide formation, either when burning oil or when burning gas, may be reduced by 50 per cent.[6]

Effluent Treatment

Among the most promising control developments are those affecting the removal of contaminants, particularly sulfur oxides and particulates, from the effluent gases. For sulfur dioxide removal alone, some 50 to 60 different laboratory methods have been investigated. Of these, only a few are of any practical significance. Others are so costly that in full scale operation more energy would be required for the removal of the contaminants than could be produced by the power plant. The few remaining possibilities are still being investigated.

Table XIII—Emission Factors for Oil Fired Combustion Equipment

Reference No.[a]	Pounds per Barrel of Fuel Oil				
	Combustion Contaminants	Sulfur Dioxide	Sulfur Trioxide	Aldehydes (as Formaldehyde)	Oxides of Nitrogen (as NO_2)
2	0.672	6.552	0.042	0.084	0.605
3	0.672	3.528	0.084	0.084	0.882
4	0.756	8.694	0.126	0.042	5.552
5	1.218	9.114	0.126	0.168	3.053
8	0.378	1.302	0.084	0.126	0.685
9	1.722	4.620	0.001	1.008	0.622
10	1.134	0.011	0	0.168	2.205
11	0.672	7.308	0.084	0.084	5.112
12	0.420	2.436	0.013	0.084	0.564
13	1.344	2.394	0	0.084	0.349
14	0.126	3.528	0	0.042	1.080
15	3.528	19.698	0.336	0.042	5.198
16	0.420	9.156	0.084	0.084	3.625
17	0.462	13.356	0.084	0.168	4.147
18	0.630	15.330	0.084	0.084	3.142
19	1.092	6.804	0.294	0.462	3.650
26	0.672	3.318	0.008	0.126	0.525
27	0.008	0	0	0.016	0.189
30	0.210	0.005	0	0.042	0.357

[a] Numbers refer to equipment listed in Table IX.

Concerning the reduction of plume opacity and removal of particulate matter from flue gases, experiments have shown that the most attractive method for control is the use of electrical precipitators. The Southern California Edison Company recently completed the first full scale prototype precipitator unit at its El Segundo steam station. Experiments in which alkaline additives are injected into the flue gas stream ahead of the precipitator unit are also under way in order to determine whether a reduction of sulfur oxides can also be accomplished.

Substitution of Natural Gas for Fuel Oil

The substitution of natural gas for fuel oil would result in the elimination of particulate matter and sulfur compounds, as well as a marked reduction in oxides of nitrogen from the stack effluent. Thus, the simplest improvement that could be made to reduce air contaminants from the combustion of fuels would be to discontinue the use of fuel oil in favor of natural gas. In view of this, concerted effort is being made by the electric generating agencies to increase their allotment of natural gas supplies.

Conclusions

The demand for thermal energy in Los Angeles County is increasing at an astounding rate, and from all indications will at least double within the next eight to ten years. Essentially, all of this demand is being met with petroleum and natural gas fuels.

From an air pollution point of view, petroleum fuels are totally undesirable as an energy source because the burning of such fuels in power plants and various other industrial activities results in emissions to the atmosphere each day of hundreds of tons of air contaminants. Since this constitutes a major source of air pollution, every possible effort must be asserted to assure to this area the availability of increased supplies of natural gas.

Although considerable progress has already been made, a great deal of engi-

Table XIV—Sources and Quantities of Emissions of Sulfur Dioxide, Oxides of Nitrogen and Aerosols in Los Angeles County

Source	Contaminant Emissions, Tons per Day			Per Cent of Total		
	Oxides of Sulfur as SO_2	Oxides of Nitrogen as NO_2	Aerosols	SO_2	NO_2	Aerosols
Combustion of fuels	310	250	35	68	36.1	40
Automobiles, trucks and buses	50	435	30	11	62.9	34.5
Metallurgical industries	n	n	6	—	—	7.0
Petroleum refining	50	5	5	11	0.7	5.8
Mineral industries	n	n	4	—	—	4.6
Refuse incineration	n	2	4	—	0.3	4.6
Chemical industries	46	n	3	10	—	3.5
Total	456	692	87	100	100	100

n—Negligible (less than 0.1 ton per day).

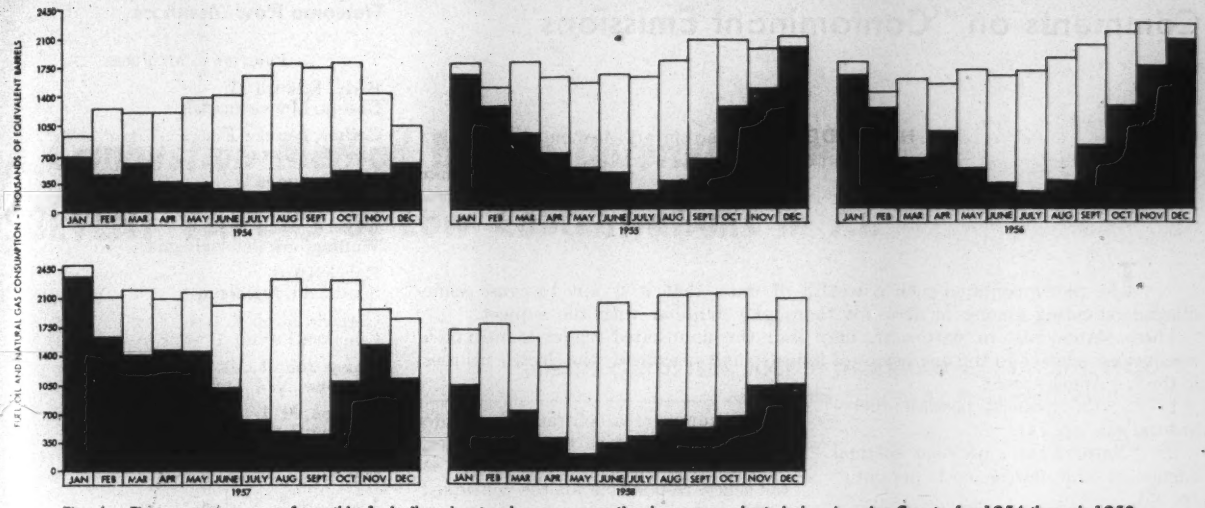

Fig. 4. Five-year summary of monthly fuel oil and natural gas consumption by power plants in Los Angeles County for 1954 through 1958.

neering research and development are still needed to render feasible the several methods proposed for controlling emissions of air contaminants from the burning of fuel oil. In the interim, it will be necessary to allocate the use of available fuels in such a way as to minimize air pollution from this source.

There is general agreement that the most desirable fuel for power generation is natural gas. It is also apparent from the forecasts of thermal energy requirements and natural gas supplies for the Los Angeles area that there will not be enough gas to meet the estimated demand, under all circumstances. The variable annual demands for natural gas by firm users will require that under certain conditions some fuel oil be burned by interruptible users. Efforts will be directed, however, toward reducing this use of fuel oil to a minimum.

Since oxides of nitrogen play an important role in the photochemical reactions occurring in the atmosphere of Los Angeles County, it is essential that steps be taken as soon as possible to determine the degree to which emissions of nitrogen oxides can be controlled. Toward this end, the APCD has initiated a Joint District, Federal, and State program with the co-operation of local power generating agencies and oil refinery industries for the purpose of obtaining the necessary information upon which future control policy can be based. Should this program be successful, a rule establishing maximum permissible limits on the emission of oxides of nitrogen from stationary sources can be expected in the foreseeable future.

Investigations will be continued to supplement the data already obtained concerning emissions from the combustion of liquid and gaseous fuels. Only when adequate information is available will the control of air contaminants from this source become a reality.

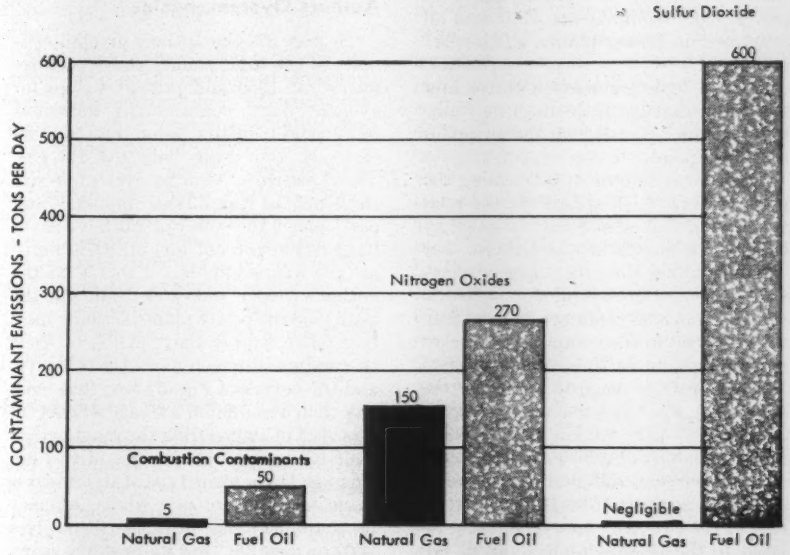

Fig. 5. Comparison of contaminant emissions from fuel oil and natural gas, based on annual daily average fuel usage for 1958 by interruptible industrial sources in Los Angeles County.

REFERENCES

1. Carl A. Trexel, Jr., California Requirements for Thermal Energy, Exhibit 5924-2, presented before Calif. Public Utilities Commission, July 29, 1957.
2. A. J. Haagen-Smit and W. L. Chadwick, Some Findings Toward Control of Air Pollution from Combustion of Fuel Oil and Natural Gas, November 18, 1958, Washington, D. C., National Conference on Air Pollution.
3. H. DeVorkin and B. J. Steigerwald, Emissions of Air Contaminants from Boilers and Process Heaters, Joint District, Federal and State Project for the Evaluation of Refinery Emissions, Report No. 7, June 1958.
4. A. J. Haagen-Smit and W. L. Chadwick, op. cit., page 6.
5. D. H. Barnhart and E. K. Diehl, Control of Nitrogen Oxides in Boiler Flue Gases by Two-Stage Combustion. Presented at the 52nd Annual Meeting of the Air Pollution Control Association, Los Angeles, Calif., June 25, 1959.

Comments on "Contaminant Emissions"

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State of California

The paper contains such a wealth of data that it is apt to cause some misunderstanding among readers not thoroughly familiar with the subject.

Three statements, in particular, may lead the uninitiated reader to mistaken conclusions relative to the operations of industry and specifically the electric utilities in the Los Angeles area:

1. "...the cleanest possible fuel—natural gas" (p. 34).
2. "Natural gas...provides thermal energy at the lowest cost per btu" (p. 35).
3. Charts and graphs indicating an excess of supply of natural gas over power plant requirements while fuel oil is burned in power plants. (Table III and Fig. 1.)

There is little argument with the first statement that gas is the most desirable fuel for power plants from the air pollution standpoint.

The second statement concerning the price of gas is misleading since the relative cost of fuel oil and natural gas fluctuates with the market conditions. For example, at the time the paper was presented the cost of natural gas to electric utilities was 32.0 cents per million Btu, while fuel oil in the competitive market could be bought for 26.5 cents per million Btu. Effective August 1, 1959, the price of gas is expected to increase to 33.4 cents per million Btu. When actual combustion efficiencies are considered, the price differential in favor of oil is even greater. This shift in relative cost of the two fuels may be directly related to the passage of Rule 62 in Los Angeles County. In spite of the higher price of natural gas, many industries, especially the electric utilities, in order to minimize air pollution have voluntarily used natural gas as much as is feasible, and have made strenuous efforts to increase the available supply.

Utilities Prefer Fuel Oil

Charts and graphs showing an oversupply of natural gas could indicate that the utilities prefer the use of fuel oil. It should be pointed out that in spite of all the gas available, potentially available, certificated, or whatever the classification may be, the electric utilities are not guaranteed one single cubic foot of gas by contract. The gas supply may be discontinued by the gas supplier, at will, on a few minutes' notice. It is not logical for an electric utility to rely solely on such an interruptible gas supply. The only possible safeguard is a contract between the utility and the fuel oil supplier; a contract which, unlike the contract with the gas supplier, makes two parties, the buyer as well as the seller, responsible for the continued fuel supply.

Authors Overemphasize

On page 37, the authors give an estimate of the total annual power requirements for 1959 and present values for average daily contaminant emissions from power plants using fuel oil exclusively and using only natural gas. These statistics seem to overemphasize the benefit of Rule 62 since industry, and particularly the power plants have never burned 100 percent fuel oil when natural gas was available. Table V of the author's paper indicates that for the year 1958 the power plants actually used fuel oil to supply only 33.8% of their thermal requirements in the County, and the curves of Fig. 5 show that even less than the annual average of fuel oil was used in 1958 during the months that Rule 62 now forbids the use of fuel oil. On page 41 the same type of statement is made for industry as a whole, whereas in actuality the authors themselves state on page 35, "For the past five years, fuel oil has supplied from 30 to 35 per cent of the area's industrial fuel requirements." Thus even before the limitation on the use of fuel oil was imposed, industry was using far more gas than fuel oil. Therefore, it seems reasonable that the maximum reduction in the release of air pollutants would be the difference between the low fuel oil use of the comparable months of 1958, before the limitation became effective, and the no oil use of 1959.

We believe that with the appropriate explanation the author's work is an excellent account of the proportions of contribution of fuel burning to air pollution. The wealth of statistical and other information contained in the paper is indicative of the prodigious amount of work that has been accomplished by the Los Angeles County Air Pollution Control District. The authors are to be thanked for their work in making available these sorely needed basic data.

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Atlanta, Georgia

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Enoch, Otto
Southfield, Michigan

Gerlach, Jacob A.
Cincinnati, Ohio

Haley, John L., Jr.
Syracuse, New York

Jackson, M. L.
Moscow, Idaho

Limgrover, John K.
Pittsburgh, Pennsylvania

Lockhart, F. Norton
Philadelphia, Pennsylvania

Lynch, Robert, Jr.
Hartford, Connecticut

Minch, Virgil A.
Chillicothe, Ohio

Nichols, Luther A.
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Noda, Hiroshi
Nagoya City, Japan

Pasini, Albert C.
Detroit, Michigan

Payne, Robert C.
Los Angeles, California

Phillips, Robert E.
Palo Alto, California

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York, Pennsylvania

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Skove, Philip W.
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Melbourne, Australia

A Combustion Method for the Determination of SOLVENT VAPORS at Low Concentrations in Air*

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Los Angeles County Air Pollution Control District

Introduction

Adequate methods for the quantitative determination of single and mixed solvents at low concentration in air discharge samples taken from industrial plants have not been generally available in the past. According to a survey[1] made by the Los Angeles County Air Pollution Control District in 1955, approximately 800,000 lb of organic vapors were emitted from industrial operations to the atmosphere within the County. Surface coating operations contributed in excess of 25 percent of these emissions. The many coating units in the county produce from as little as one pound to as much as 3130 lb of solvent vapor emission per day per unit.[2]

New or improved methods of organic vapor analysis must be developed to test adequately the efficiency of devices to collect or control the emission of solvents from these diverse operations.

Surveys made by the Engineering Division of the District show that the discharge of organic vapor from protective coatings operations normally occurs in the range of 100–200 ppm. The maximum allowable concentrations are dictated by local fire regulations and by the state industrial code.

The realization of a 90–95 percent efficiency of control imposes on the analytical method the requirement that concentrations as low as five ppm be determined with reasonable accuracy.

Because of the considerable number of solvents used in the formulation of protective coating finishes, a direct method of analysis which would yield the important information of total weight of emission and the weight of emission controlled is a matter of primary concern.

The method presented in this paper can be applied to securing this information from simple operations such as spray coating.

More difficult analytical problems are encountered in the analysis of emissions from bake ovens and lithographing ovens. Such operations usually produce quantities of oxygenated compounds as aldehydes and organic acids and organic particulate matter. Direct gas fired ovens, in addition, produce large quantities of carbon dioxide and condensable water vapor to further complicate the analytical problem.

The development work reported here has been directed toward solving these problems.

Development of Method

Various direct methods of analysis were evaluated first.[3–6] All were found to offer serious objections for routine application. Weight gain of activated carbon on absorption of solvent vapors suffers from the lack of a convenient method for the separation of water vapor from such oxygenated solvents as methanol, ethyl acetate, etc. Certain instrumental methods are too specific for general use. For instance, detection of aromatic vapors by ultraviolet absorption,[7] while rapid and extremely sensitive, cannot be applied to the detection of aliphatic solvents. Nondispersive infrared analyzers with a catch-all type of sensitization in terms of hexane still have quite unequal response to certain classes of compounds as ketones and esters.

Early in the consideration of analytical methods to measure the emission of organic solvent vapors, the concept of a combustible carbon index of solvent concentration was advanced. Proposed was the measurement of the increase in CO_2 concentration after combustion of a sample of the vapors in a suitable apparatus. In this method the combustible CO_2 concentration is the difference between total CO_2 and CO_2 present in the original sample.

The first development work attempted to devise a method of combustible carbon analysis based on the well-known micro-combustion method of Pregl[8] with a suitable modification for handling gaseous samples. A procedure was evolved using parallel absorption trains to measure the CO_2 content before and after combustion. One incorporated the standard heated micro-combustion tube and catalyst filling; the other contained a "cold" unfilled combustion tube of the same volume. Mercury was used to displace the sample. Experimental work indicated the standard Anhydrone-Ascarite absorption train is uniquely selective for CO_2 and that background CO_2 concentration could be determined accurately in the presence of a wide variety of hydrocarbons and oxygenated compounds. Although sufficient precision was attainable by this method, the high degree of skill involved in the successful use of microanalytical gravimetry and the limited number of analyses that could be performed (a maximum of six per day) by a single analyst eliminated the method from serious consideration.

During the period of the micro-combustion experimentation, a CO_2 sensitized infrared analyzer was ordered capable of determining CO_2 concentrations in the ranges 0–5000 ppm and 0–30,000 ppm. It was hoped that a rapid method of analysis could be developed with this instrument having the requisite accuracy and sensitivity and without the necessity to resort to freeze-out techniques or other methods of sample concentration. Although manufacturing literature and recommendations indicated use of this instrument only for continuous monitoring, the need existed for an instrument adaptable to analysis of small volume samples. Consideration of the operation of a

* Presented at the 52nd Annual Meeting of APCA, June 21–26, 1959 Statler Hotel, Los Angeles, Calif.

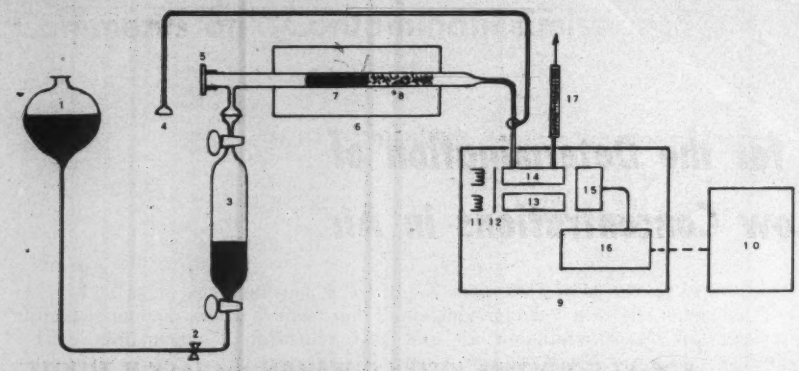

Fig. 1. Diagram of apparatus. (1) Mercury supply. (2) Pinch clamp. (3) Gas sample tube. (4) Bypass line. (5) Serum stopper. (6) Combustion furnace. (7) Platinum gauze. (8) Copper oxide. (9) Infrared analyzer. (10) Recorder. (11) Sources. (12) Chopper. (13) Comparison cell. (14) Sample cell. (15) Detector. (16) Amplifier. (17) Rotameter.

process employing a control device indicated that three points must be simultaneously sampled: (1) the inlet air to the process; (2) the inlet to the control device; and (3) the outlet to the control device. It is apparent that the combustible carbon concentration at all three points would have to be determined simultaneously and that the expense of three instrumental setups would have to be borne if one desired to determine by continuous monitoring the efficiency of such a process employing a control device. Accordingly, experimental work was directed toward developing a method of small volume analysis of samples collected in MSA type gas sample tubes and employing a simplified, compact combustion unit.

The use of a combustion-infrared CO_2 detector for hydrocarbon analysis has been described by Martin and Smart.[9] Heaton and Wentworth[10] also described the successful use of this detection system. The combustion unit used in their experimental work on auto exhaust was also used in the initial experimental work of this project: "Permatherm" catalyst tube operated at 900°F. Samples contained in MSA type gas sample tubes were displaced with mercury through the heated catalyst and into the infrared absorption cell. This tube was finally abandoned because of various problems arising in its use. The combustion tube finally adapted is very similar to the standard tube commonly used in micro-analytical work.

Two possible methods of small volume analysis have been considered. One method would relate the area under a peak traced on the recorder chart to the CO_2 concentration as a sample of known volume is passed through the apparatus. A separate sample would have to be analyzed in the same manner to determine background CO_2 concentrations. The second method involves the attainment of constant CO_2 reading as a sample is flowing through the combustion unit and infrared detector under equilibrium conditions. This second method was successfully developed to handle samples of between 200 and 500 cc total volume.

Analytical Methods

Apparatus

Figure 1 illustrates schematically the components of the equipment and their arrangement. The combustion tube is constructed of Vycor tubing, 10.5 mm O.D. and 300 mm long, fitted with a #12/2 Vycor socket side arm. The front end is open to provide for ease of packing and is plugged with a short length of glass rod wrapped with aluminum foil. A serum stopper is placed over the end to make a vapor-tight seal. Catalyst packing of this tube consisted of a section filled with copper oxide pellets preceded by a three-inch length of platinum gauze roll. The combustion tube is placed in a Fischer micro-combustion furnace operated at 700°C. The infrared analyzer is a MSA Model #200, deflection type, sensitized for CO_2. A dual range of 0–5000 ppm CO_2 and 0–30,000 ppm CO_2 is provided simply by making an approximate 6:1 change in amplifier gain. Normal gain is 4x for the 0–5000 ppm range. Sample cell dimensions are 0.5 in. I.D. x 1.8 length, giving a retention volume of approximately 5 cc. Total capacity of the combustion tube-sample cell system with the necessary connecting tubing is approximately 35 cc. A Brown Instrument Model 153, 0–100 mv null balance type recorder geared for a chart speed of four inches per hour receives the output of the analyzer. A 0–100 cc/min rotameter mounted on the outlet of the sample cell of the analyzer indicates a sample flow rate. MSA type 250-cc gas sample tubes were modified by sealing a #12/5 ball joint to one end. As illustrated in Fig. 2, this enabled one to attach the sample tube directly to the combustion tube without the need for rubber or Tygon tubing, the use of which proved so detrimental to accurate analysis. (See Discussion.)

Fig. 2. Recorder, combustion unit and infrared analyzer.

Procedure

Samples are collected in the modified evacuated MSA tubes. After attachment to the combustion tube a sample flow rate of approx 20 cc/min is maintained by regulating the introduction of mercury into the sample tube. Flow is first directed through the combustion unit. Initial instrument response will be noted after approximately 30 cc of sample has been displaced with mercury and an equilibrium reading may be obtained after the displacement of about 70 cc of sample. Usually two to three minutes of flow at equilibrium conditions are sufficient to produce an accurately readable chart trace. The combustion unit is then bypassed and an equilibrium chart trace produced to establish the background CO_2 concentration.

Purging the instrument with nitrogen between runs serves to separate analyses on the chart so they may be easily distinguished. A check on the zero adjustment is thus also obtained so that the absolute value of the background CO_2 concentration may be determined.

The MSA Model 200 infrared analyzer has a nearly linear response in the

range 0–2000 ppm CO_2. The equivalent calibration in terms of MEK (methyl ethyl ketone) and toluene is 4.5 ppm and 3.1 ppm, respectively, so that the results of analyses may be read from the charts practically on inspection. This is in contrast to the comparatively slow calculation of peak areas necessary in integral methods as employed in gas chromatographic analysis. Figs. 3 and 4 are illustrations of typical analytical records. The analysis of six grab samples of the outlet of a carbon unit collecting MEK vapors and of six grab samples of the inlet to a carbon unit collecting toluene vapors is shown.

Experimental Results

Preparation of Known Solvent Concentrations

MEK and toluene were prepared in concentrations of 900–100 ppm by injection of measured volumes of liquid solvent into a 50-l flask. Low concentrations in gas sample tubes were prepared from this supply by dilution. No difficulty was experienced with this method in preparing accurately known concentrations of solvents having a volatility equal to or higher than that of *n*-octane. Although contact with rubber or plastic in the form of stoppers and tubing was minimized, accurately known concentrations of mineral spirits with a boiling range including that of *n*-decane could not be prepared. This is illustrated in Table I comparing various calculated and determined concentrations of *n*-octane and *n*-decane.

Absorption Effects

Some explorations of the absorption of low concentrations of various solvents on plastic materials were made in recognition of the difficulties this effect placed on the development of the analytical method. A one-half inch length of gum rubber tubing was found to absorb most of the mineral spirits in a 100 cc sample at concentrations of 0–100 ppm when passed through at flow rates of 10–20 cc/min. No appreciable absorption of MEK vapors in a two-inch length of tubing occurred at similar flow rates. To eliminate these losses of sample, a direct ball and socket joint was provided between the sample tube and the combustion tube. Experimentation with gas sample tubes having greased stopcocks proved that samples of low boiling organics could be collected and stored at least 24 hr without loss.

Combustion Efficiency

Experimentation proved that no difficulty existed in achieving the complete oxidation of organic vapors with the described catalyst filling at an operating temperature of 700°C and at flow rates up to 35 cc/min. The patented

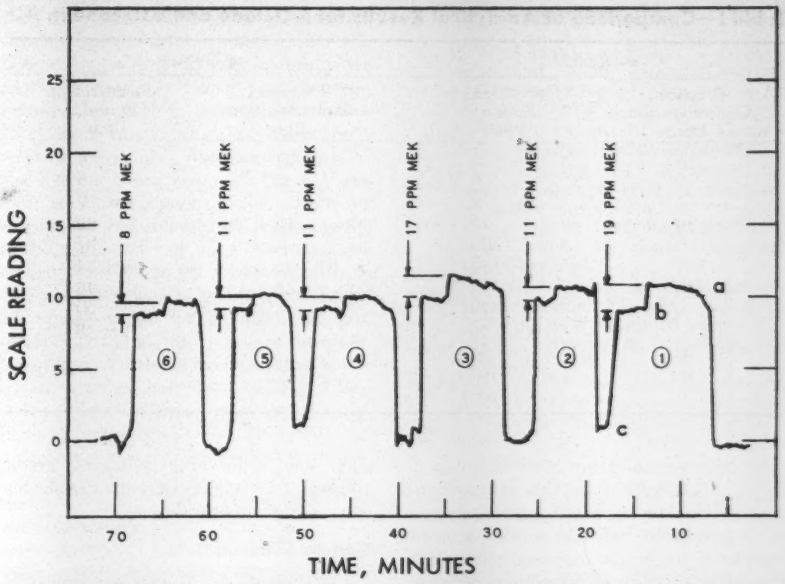

Fig. 3. Analysis of six grab samples of the effluent of a paint spray booth after a carbon adsorption unit. Chart speed: four inches per hour. Solvent is MEK. (a) Sample passed through combustion unit. (b) Bypass of combustion unit. (c) Zero gas (nitrogen) purge.

"Permatherm" catalyst tube, of the Burrell Corporation, while furnishing extremely efficient combustion, has an absorbent packing (probably silica gel) at either end which remained partly outside of the heater unit. The maximum operating temperature was restricted to 450°C because of the Pyrex tube used in construction. Strong evidence was obtained that additional CO_2 adsorption effects were possible with a catalyst at this temperature. For these reasons and because the design made it awkward to use, the conventional horizontal combustion unit was adapted.

Effect of Water Vapor

Since a certain amount of cross sensitivity to water vapor exists and since most samples obtained in air contain 10,000–20,000 ppm of water vapor, an error in an absolute reading will result. In obtaining a differential reading this error is assumed to be canceled if the change in concentration of the total water vapor content due to oxidation of the solvent is small. This is actually so

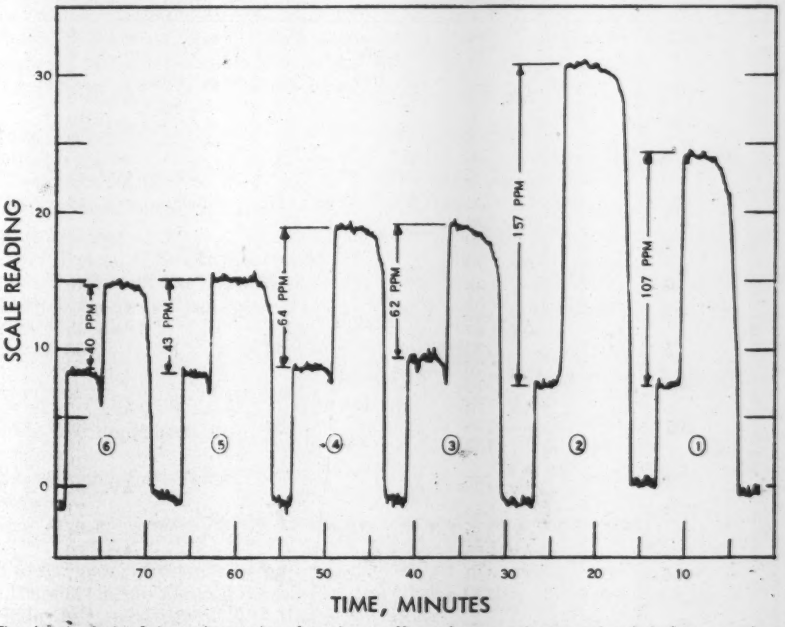

Fig. 4. Analysis of six grab samples of a toluene effluent from a paint spray booth before a carbon adsorption unit.

Table I—Comparison of Analytical Results for *n*-Octane and *n*-Decane in Air

n-Octane		*n*-Decane	
Prepared Concentration, Ppm	Concentration Found, Ppm	Prepared Concentration, Ppm	Concentration Found, Ppm
10	8	10	5
	8		8
	Av. 8		Av. 7
19	17	40	22
	20		27
	Av. 19		Av. 24
80	73	67	45
	79		50
	Av. 76		Av. 48
96	97		
	107		
	Av. 102		

when the concentration of solvent vapor is low. The validity of this assumption was proved by repeatedly passing solvent free air containing normal atmospheric water vapor concentrations alternately through the combustion train and then through the bypass of the combustion unit into the infrared instrument. No difference in CO_2 concentrations as detected by the infrared analyzer could be observed. An error due to unburned organics entering the absorption cell during the determination of background CO_2 concentration may occur if appreciable cross sensitivity exists. Experimentally determined cross sensitivities to most organics are of such low order (for instance, about 100,000:1 for MEK) that error from this cause is not measurable.

Carbon Monoxide

Concentrations of carbon monoxide in local atmospheres up to 60 ppm were readily detected by the combustion technique. Undoubtedly, varying quantities of organics contributed to this total measurement in terms of combustible carbon. All immediate sources of local air used in the preparation of known concentrations of organic vapors had to be checked and a correction made for its variable content of combustible carbonaceous material.

Table II—Analysis of Prepared Samples of MEK and Toluene in Air

MEK		TOLUENE	
Prepared Concentration, Ppm	Concentration, Found, Ppm	Prepared Concentration, Ppm	Concentration Found, Ppm
10	14	8	8
	10		6
			8
	Av. 12		Av. 8
10	8	8	10
	8		10
	8		
	Av. 8		Av. 10
30	30	17	16
	30		
	30		
	Av. 30		
38	38	19	19
	32		19
	Av. 35		Av. 19
75	70	33	35
	70		35
	70		
	Av. 70		Av. 35
185	190	37	38
	195		38
			38
	Av. 193		Av. 38
370	355	67	71
	355		67
	Av. 355		Av. 69
465	440	188	187
	380		193
			189
	Av. 410		Av. 190

Discussion

Precision of Method

The most common causes of error inherent in securing an absolute reading of CO_2 concentration are largely eliminated by the present method. Changes in calibration (span) have been found to be small over long periods of use; further, small errors in setting the instrument span in no way affect the precision. Manufacturers of nondispersive infrared analyzers usually specify a precision of the order of one percent of full scale for most sensitizations. Strip charts for Brown recorders may be provided with 200 ruled lines. These charts are hence easily readable with an accuracy of one-fourth of one percent of full scale. Since zero drift in the present instrument is negligible over the 15 min. required for an analysis, and since errors due to electronic noise are largely canceled in obtaining a differential CO_2 reading, it has been found possible in many instances to attain a precision equal to the accuracy with which a 200 line chart may be read. The results of typical analyses of known concentrations of toluene and MEK vapors in air are presented in Table II. Standard deviations calculated from many series of analyses have been found to be approximately 20 ppm as CO_2. The stated precision, of course, holds only for the case where the total concentration of CO_2 is less than the full scale range of 5000 ppm.

Independent analytical methods of sufficient accuracy in the range of concentrations of interest were not available to provide a primary standard of comparison. Inspection of the work accomplished certainly indicates an absolute accuracy of at least 95 percent in the analyses of low boiling solvents. An illustration of the reproducibility of an analytical result is presented in Fig. 5.

Adsorption Effects

Solvent loss due to adsorption from collected samples appeared to be the most serious problem associated with a small volume technique. Rubber and plastic tubing were eliminated from the analytical apparatus and also from the sample collection points of an experimental spray booth. Nevertheless, results indicate that successful analyses appear to be limited to lower boiling solvents. A superior sampling system from sources containing vapor concentrations of high boiling solvents is one in which a sample is continuously aspirated through the sample tube. In this way the interior surfaces of the sample bulb may be brought to equilibrium with the solvent at the concentration of the source. Failure of a sample containing high boiling solvents

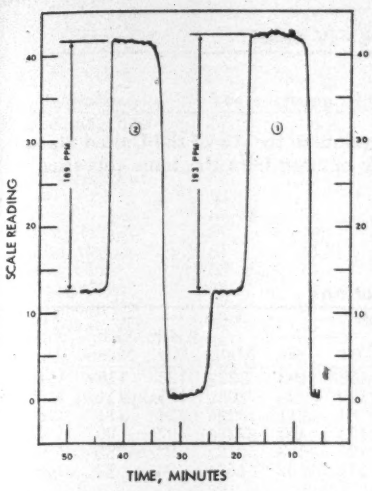

Fig. 5. Reproducibility of analyses. Duplicate samples of toluene vapors.

to reach an equilibrium reading when passed through the analytical apparatus can also be attributed to adsorption losses rather than incomplete combustion.

Limitations

The chief usefulness of the present analytical method is the determination of emissions from sources of known single solvents or of mixtures of hydrocarbon solvents. The mass concentration of a mixture of hydrocarbons (both aliphatic and aromatic) can be determined with sufficient accuracy for most purposes. Using an average formula of $CH^{1.6}$, analytical results would be five percent high if the solvent were benzene and five percent low if the solvent were hexane. Since these two solvents represent the limits of saturation and unsaturation commonly found, an analysis of a hydrocarbon solvent can thus be reported with a 95% accuracy on a weight basis. However, most oxygenated solvent mixtures found in various lacquer formulations cannot be estimated within an error of less than ±25%. Because the method can supply only limited information on emissions of mixed solvents, the present combustion-infrared CO_2 analyzer has been considered for the detection system for chromatographic analysis. The relative insensitivity of the CO_2 analyzer to water vapor is an especially attractive consideration. The precision achieved by the present method restricts the total combined CO_2 concentration to a maximum of 5000 ppm. Thus the emissions from a direct-fired source such as a bake oven cannot be measured accurately. This restriction can undoubtedly be removed with a gas chromatographic procedure capable of separating high background CO_2 concentrations from low concentrations of solvent vapors.

REFERENCES

1. R. G. Lunche, A. Stein, C. J. Seymour, and R. L. Weimer, *Chemical Engineering Progress*, **53**, pp. 371–376 (August, 1957).
2. Air Pollution Control District, County of Los Angeles. Unpublished data.
3. G. A. Burrell, and G. W. Jones, "A Vapor Pressure Method for Estimating the Concentration of Organic Vapors Such as Gasoline in the Air," U. S. Bureau of Mines Technical Paper 87 (1916).
4. W. A. Cook and A. L. Coleman, "Determination of Solvent Vapors in Air by Means of Activated Charcoal," *J. Indust. Hygiene & Toxicology*, **18**, 194 (1936).
5. K. Kay, G. M. Reece, and P. Drinker, "A New Vapor Pressure Instrument for Determining Organic Solvents in Air," *J. Indust. Hygiene & Toxicology*, **21**, 270 (1939).
6. P. E. Palmer and E. R. Weaver, "Thermal Conductivity Method for the Analysis of Gases," N.B.S. Technical Paper No. 249 (1924).
7. V. F. Hansen, "Ultraviolet Photometer: Quantitative Measurement of Small Quantity Traces of Solvent Vapors in Air," *Ind. & Eng. Chem., Anal. Ed.*, **13**, 119 (1941).
8. F. Pregl, "Die Quantitative Organische Mikroanalyse," J. Springer, Berlin (1930).
9. A. E. Martin and J. Smart, (letter to Ed., gas phase chromatography) *Nature*, **175**, 422–3 (1955).
10. William B. Heaton and Joseph T Wentworth, "Exhaust Gas Analysis by Gas Chromatography Combined with Infrared Detection," *Anal. Chem.*, **30**, 349 (1959).

OPEN FOR SUGGESTIONS

The time is fast approaching when a new president and five new APCA Directors will be elected by the membership. You, as an individual member or company representative member of APCA, are requested to submit to the chairman or any member of the Nominating Committee, names of individuals and the offices for which you feel they are qualified. These recommendations should be received before March 10, 1960.

The members of the Nominating Committee and their addresses are as follows:

O. C. Thompson, Chairman
Co-ordinator Waste Abatement
Union Carbide Chemicals Co.
Div. of Union Carbide Corp.
P. O. Box 8004
S. Charleston 3, West Virginia

Dale Hutchison
Assistant to the Director
Physical Sciences Division
Stanford Research Institute
Menlo Park, California

John T. Doyle,
Vice President
Aerotec Industries, Inc.
Greenwich, Connecticut

John Hodges
Chief, Bureau of Smoke Abatement
Div. of Air Pollution Control
14101 Lake Shore Blvd.
Cleveland 10, Ohio

W. E. Tidmore
Air Pollution Control Engineer
Building Department
800 City Hall
Atlanta, Georgia

The offices for which this committee is to select nominees are:

1. President—to serve one year.
2. Five Directors—to serve according to the following schedule:
   - 2 control officials to serve three years.
   - 1 control official to serve one year as a replacement for Dr. Greenburg who moves into the research and educational category.
   - 2 industry representatives each to serve for three years.

Retiring Board members are: Milton Reizenstein and Thomas Purcell—control officials; O. C. Thompson, chemical, and Charles M. Heinen, automotive—industry; and Richard F. O'Mara—consulting.

Addenda

The following table is a continuation of Table VI in the paper titled "Particulate Pollutants in the Air of the United States" which appeared in the November JOURNAL. The material shown here was inadvertently omitted from the table appearing on page 141 of that JOURNAL.

Table VI—Suspended Particulate Matter—Urban Stations

Station	Years	No. of Samp.	Micrograms per Cubic Meter — Frequency Distribution, percent									Max.	Arith. Avg.	Geo. Mean	Std. Geo. Dev.
			Min.	10	20	30	40	50	60	70	80	90				
Charlotte, N. C.	57	25	45	67	79	95	105	118	129	145	158	193	322	125	115	1.499
	58	25	43	61	68	89	96	109	118	139	179	228	308	123	111	1.666
	57–58	50	43	61	72	89	100	111	124	139	164	211	322	124	111	1.601
Winston-Salem, N. C.	57	26	28	55	61	72	87	93	98	106	129	152	228	97	90	1.486
Asheville, N. C.	58	25	45	49	52	68	74	81	85	112	125	193	212	93	85	1.667
Greensboro, N. C.	58	22	34	41	52	68	72	79	85	93	118	132	156	83	77	1.550
San Juan, Puerto Rico	57	21	45	52	55	57	60	68	75	80	85	118	132	73	69	1.352
Norfolk, Va.	57	25	60	79	85	96	103	110	115	126	135	156	168	111	109	1.299
	58	26	48	67	76	90	100	111	129	147	171	186	209	119	113	1.527
	57–58	51	48	72	81	91	102	111	118	133	152	176	209	115	110	1.418
Richmond, Va.	57	26	50	61	65	70	85	93	100	112	129	139	232	101	91	1.421
Hampton, Va.	58	25	27	39	44	57	61	69	75	85	100	118	162	75	67	1.543
Charleston, W. Va.	57	23	44	61	75	82	100	129	179	269	374	481	655	207	151	2.395
	58	23	45	52	85	91	97	152	179	228	269	441	708	192	145	2.216
	57–58	46	44	64	75	88	98	132	179	242	346	441	708	199	148	2.256
Wheeling, W. Va.	57	25	137	146	153	164	176	193	205	222	269	305	344	201	197	1.344
Birmingham, Ala.	57	25	50	61	81	93	100	114	139	171	186	228	285	129	120	1.667
	58	21	46	61	100	109	118	164	193	249	346	441	640	209	165	2.133
	57–58	46	46	61	85	100	109	125	164	183	228	317	640	166	135	1.850
Mobile, Ala.	58	25	62	76	85	94	100	118	164	269	317	441	485	184	152	2.094
Tampa, Fla.	57	26	34	55	61	67	70	76	81	85	94	100	168	79	75	1.266
	58	26	39	72	76	83	87	94	100	107	118	145	164	99	95	1.300
	57–58	52	34	58	67	74	79	84	90	96	108	139	168	89	85	1.362
Miami, Fla.	57	25	31	45	48	52	56	61	65	70	79	95	106	63	61	1.333
Jacksonville, Fla.	58	26	46	52	57	65	72	93	106	118	139	179	220	101	90	1.653
Atlanta, Ga.	57	26	50	72	79	87	91	98	109	118	134	147	228	105	101	1.331
	58	21	35	61	75	82	93	112	125	139	205	228	268	124	113	1.696
	57–58	47	35	67	77	85	93	103	113	127	145	202	268	114	106	1.497
Columbus, Ga.	57	26	37	57	65	75	82	104	114	122	135	152	209	102	95	1.499
Augusta, Ga.	58	25	34	44	49	58	72	78	81	100	118	205	225	92	80	1.740
Macon, Ga.	58	25	20	44	52	63	68	89	96	129	152	193	336	105	88	1.816
Jackson, Miss.	57	24	15	22	54	57	61	68	75	85	100	139	198	76	66	1.777
	58	24	39	45	49	52	72	85	93	118	132	156	199	91	81	1.707
	57–58	48	15	44	51	56	63	74	85	98	118	145	199	84	75	1.610
Columbia, S. C.	57	24	55	72	82	87	94	98	109	129	139	164	209	111	104	1.375
	58	24	42	61	87	91	96	100	106	115	147	193	263	116	105	1.459
	57–58	48	42	68	85	89	94	99	109	123	143	164	263	114	104	1.383
Greenville, S. C.	57	26	55	61	68	77	82	91	100	139	154	164	285	111	98	1.528
Chattanooga, Tenn.	58	23	90	100	147	164	183	205	216	228	269	520	532	244	204	1.680
Knoxville, Tenn.	57	26	68	81	93	105	110	118	139	152	179	228	245	136	127	1.477
Nashville, Tenn.	57	26	71	81	89	100	109	123	139	147	160	193	317	134	122	1.408
	58	26	48	85	100	114	125	147	174	193	285	317	415	179	155	1.709
	57–58	52	48	80	93	107	118	133	147	161	211	293	415	156	138	1.616
Memphis, Tenn.	58	26	59	68	74	79	83	89	94	98	112	125	154	94	89	1.262
Chicago, Ill.	58	23	94	106	139	156	174	197	205	212	220	269	335	188	180	1.385
East St. Louis, Ill.	58	22	32	100	156	179	193	238	259	317	360	441	549	251	228	1.725
Peoria, Ill.	58	26	58	79	109	132	143	153	164	205	236	253	294	165	154	1.553
East Chicago, Ind.	58	21	73	118	152	164	211	242	255	269	288	307	319	220	213	1.461
Evansville, Ind.	57	25	13	67	75	82	88	97	105	118	129	152	170	97	98	1.375
Fort Wayne, Ind.	57	26	70	79	93	106	112	121	129	134	164	211	304	134	122	1.414
Indianapolis, Ind.	57	26	87	109	121	130	136	146	157	164	186	205	260	149	147	1.275
	58	24	98	109	125	132	145	158	169	183	193	269	354	174	159	1.373
	57–58	50	87	109	123	131	139	150	162	176	190	228	354	161	152	1.317
Gary, Ind.	58	26	93	132	145	164	228	269	346	391	441	494	945	306	261	1.793
Detroit, Mich.	57	23	48	85	100	107	114	132	147	164	193	228	303	148	134	1.470
	58	25	54	79	93	107	114	129	139	164	200	221	246	139	131	1.506
	57–58	48	48	81	97	105	114	127	143	164	197	219	303	143	131	1.485
Kalamazoo, Mich.	57	25	37	42	47	61	65	72	85	96	118	164	181	83	76	1.677
Lansing, Mich.	57	26	34	54	59	72	79	90	104	111	125	139	152	91	88	1.479
Flint, Mich.	57	26	70	93	100	109	115	124	133	139	176	187	235	134	127	1.324
Jackson, Mich.	58	24	11	29	37	55	65	72	76	83	89	100	128	68	62	1.603
Saginaw, Mich.	58	26	44	61	68	85	90	98	109	118	131	139	186	101	96	1.397
Cincinnati, Ohio	57	26	72	85	93	109	122	135	147	156	170	181	237	134	129	1.368
	58	24	89	90	98	109	123	129	134	147	164	228	319	143	130	1.391
	57–58	50	72	88	96	109	123	131	139	153	168	189	319	138	129	1.355
Youngstown, Ohio	57	26	63	85	100	118	139	158	193	216	255	293	406	180	159	1.661
	58	26	79	93	118	131	139	147	156	161	193	228	391	157	147	1.365
	57–58	52	63	85	105	127	141	151	160	186	228	269	406	169	152	1.540
Canton, Ohio	57	26	70	107	114	132	145	164	200	214	249	281	304	182	169	1.504

Table VI—Suspended Particulate Matter—Urban Stations (*Continued*)

Station	Years	No. of Samp.	Micrograms per Cubic Meter — Frequency Distribution, percent: Min.	10	20	30	40	50	60	70	80	90	Max.	Arith. Avg.	Geo. Mean	Std. Geo. Dev.
Cleveland, Ohio	57	26	87	109	125	145	158	179	200	214	242	269	314	185	175	1.436
	58	25	69	100	122	132	139	170	181	202	219	255	279	165	162	1.437
	57–58	51	69	100	123	134	152	174	190	209	228	262	314	175	167	1.453
Columbus, Ohio	57	26	77	118	129	152	168	179	189	205	236	253	310	182	175	1.358
	58	26	78	109	122	132	139	147	156	161	193	228	241	153	150	1.307
	57–58	52	77	109	124	137	148	159	173	187	221	249	310	167	162	1.377
Toledo, Ohio	57	26	48	61	72	82	90	106	129	144	159	193	311	124	107	1.589
Lorain, Ohio	57	26	55	72	81	109	118	129	139	156	228	293	398	156	134	1.700
Akron, Ohio	58	26	44	79	90	102	107	114	125	139	164	228	431	143	121	1.459
Dayton, Ohio	58	23	60	72	85	90	95	104	111	118	126	139	150	103	102	1.281
Springfield, Ohio	58	24	49	61	85	100	118	125	132	152	174	211	264	129	121	1.563
Milwaukee, Wis.	57	25	64	90	100	118	131	143	152	164	211	269	367	161	144	1.507
	58	26	89	96	105	118	124	133	145	158	179	193	358	148	135	1.324
	57–58	51	64	91	105	118	127	137	149	162	183	269	367	155	141	1.458
Racine, Wis.	57	23	56	61	85	109	122	135	147	164	193	249	273	143	130	1.655
Des Moines, Iowa	57	26	77	95	105	118	145	164	186	199	216	228	458	176	154	1.459
	58	26	83	90	100	114	123	139	164	183	244	261	360	165	147	1.562
	57–58	52	77	90	102	116	135	153	172	193	228	262	458	170	152	1.544
Davenport, Iowa	58	20	71	85	93	100	109	118	132	147	164	211	276	133	123	1.414
Wichita, Kan.	57	26	41	54	59	72	79	93	109	118	131	139	332	103	90	1.502
	58	22	52	67	79	100	129	139	152	164	181	193	301	137	126	1.539
	57–58	48	41	57	69	79	93	114	127	139	159	183	332	119	106	1.601
Minneapolis, Minn.	57	26	42	52	72	88	94	109	126	135	164	193	722	146	106	1.631
	58	26	39	47	52	75	80	100	139	149	164	228	335	122	101	1.895
	57–58	52	39	47	65	79	90	105	125	143	164	228	722	134	104	1.795
Duluth, Minn.	57	25	25	52	72	82	93	123	134	156	179	228	401	126	112	1.760
St. Paul, Minn.	58	24	57	58	72	79	93	106	118	145	158	193	265	118	106	1.604
Kansas City, Mo.	57	26	70	109	122	135	145	164	179	188	211	228	436	173	160	1.348
	58	24	55	109	143	150	160	179	200	221	249	336	345	193	184	1.487
	57–58	50	55	109	129	144	155	168	186	205	224	269	436	183	170	1.404
St. Louis, Mo.	57	25	95	109	125	147	164	186	199	216	228	269	332	182	175	1.419
	58	24	89	100	114	139	150	157	164	186	211	293	324	171	160	1.461
	57–58	49	89	103	118	142	154	168	182	202	224	269	332	177	166	1.441
Omaha, Neb.	57	26	77	90	95	102	106	112	118	132	156	174	194	122	117	1.298
	58	22	45	72	76	83	100	109	118	125	136	164	230	111	105	1.390
	57–58	48	45	78	87	96	104	111	118	130	139	171	230	117	111	1.338
Lincoln, Neb.	57	26	65	72	85	105	114	126	139	156	179	193	248	132	123	1.481
Bismarck, N. D.	57	24	51	52	68	76	90	100	118	129	136	164	220	109	97	1.552
	58	26	22	31	48	57	61	79	90	100	125	139	324	93	73	1.771
	57–58	50	22	46	56	67	78	88	100	120	132	156	324	101	87	1.626
Sioux Falls, S. D.	57	26	51	52	61	68	72	82	90	95	109	129	169	87	81	1.412
	58	25	38	65	72	89	96	109	118	134	152	183	268	116	107	1.502
	57–58	51	38	52	65	72	83	93	100	115	132	164	268	101	91	1.540
Little Rock, Ark.	57	26	34	44	52	63	68	75	85	100	118	129	170	83	76	1.542
	58	26	44	55	61	66	69	79	95	106	125	139	190	91	84	1.474
	57–58	52	34	47	57	65	69	76	88	103	121	136	190	87	80	1.523
New Orleans, La.	57	26	52	61	75	82	87	94	100	112	132	179	239	108	97	1.456
	58	25	43	54	59	77	82	93	100	174	122	135	142	90	89	1.453
	57–58	51	43	55	72	79	85	93	100	113	126	139	239	100	92	1.412
Baton Rouge, La.	57	24	70	72	109	125	143	150	157	179	228	293	316	170	150	1.618
Albuquerque, N. M.	57	22	114	129	147	169	179	188	200	214	249	317	375	201	192	1.377
	58	24	52	72	100	118	156	171	186	207	221	301	360	177	157	1.681
	57–58	46	52	100	125	152	167	181	197	211	228	293	375	188	175	1.468
Tulsa, Okla.	57	20	22	41	48	55	61	75	82	100	118	139	268	87	74	1.642
	58	22	27	34	44	57	63	68	72	76	81	85	96	63	62	1.408
	57–58	42	22	37	46	56	63	70	76	80	90	118	268	74	66	1.519
Oklahoma City, Okla.	58	25	38	52	58	64	67	72	75	79	82	90	98	70	70	1.230
Ft. Worth, Tex.	58	26	47	57	64	72	77	85	93	98	109	118	159	86	83	1.338
Houston, Tex.	57	26	14	67	85	107	114	129	147	164	186	211	252	135	126	1.556
	58	25	57	74	79	85	93	103	109	118	139	193	284	116	105	1.420
	57–58	51	14	68	79	91	103	113	125	144	170	211	284	125	115	1.547
Dallas, Tex.	57	25	18	48	72	93	100	118	129	145	158	228	243	119	110	1.717
	58	22	64	67	72	85	95	106	118	132	152	164	210	113	105	1.458
	57–58	47	18	63	72	87	98	112	124	139	155	179	243	117	108	1.520
San Antonio, Tex.	57	26	28	57	65	85	100	114	129	139	164	193	630	135	108	1.628
	58	23	24	37	85	118	124	133	139	149	159	228	473	144	118	1.734
	57–58	49	24	52	72	95	114	126	133	145	161	211	630	139	114	1.649
El Paso, Tex.	57	26	82	107	114	147	164	211	242	269	305	336	613	223	195	1.642
Corpus Christi, Tex.	57	26	35	41	46	52	57	64	72	77	85	100	173	68	63	1.422
Austin, Tex.	58	26	16	55	61	68	72	82	100	122	132	139	181	93	87	1.503
Waco, Tex.	58	25	40	57	67	87	90	95	98	112	125	164	313	106	95	1.450
Denver, Col.	57	25	15	79	90	106	118	129	136	164	183	228	264	134	130	1.501
	58	25	41	57	65	85	100	107	111	118	139	193	265	110	101	1.552
	57–58	50	15	61	76	94	105	113	123	136	164	205	265	122	112	1.561
Boise, Idaho	57	26	48	72	77	85	95	109	122	131	164	179	207	115	109	1.467
	58	25	29	55	61	79	85	100	107	118	132	174	189	101	95	1.550
	57–58	51	29	55	73	81	90	104	114	126	139	176	207	108	100	1.530
Helena, Mont.	57	25	17	26	31	44	58	85	106	125	139	228	466	109	74	2.384
	58	25	18	28	31	42	48	61	68	85	109	139	377	79	59	1.922
	57–58	50	17	26	31	41	54	65	82	107	126	193	466	94	66	2.221

(*Continued on page 56*)

Table VI—Suspended Particulate Matter—Urban Stations (*Continued*)

Station	Years	No. of Samp.	Micrograms per Cubic Meter—Frequency Distribution, percent— Min.	10	20	30	40	50	60	70	80	90	Max.	Arith. Avg.	Geo. Mean	Std. Geo. Dev.
Salt Lake City, Utah	57	22	68	79	89	100	112	125	139	149	164	193	267	131	123	1 422
	58	24	44	55	64	69	79	85	95	125	139	164	229	101	91	1.555
	57–58	46	44	63	72	83	91	105	125	139	155	174	267	115	105	1.523
Cheyenne, Wyo.	57	26	22	29	34	46	49	52	59	63	68	72	130	55	50	1.431
	58	24	16	22	37	40	44	52	57	67	79	93	100	54	50	1.676
	57–58	50	16	28	36	43	48	52	58	64	71	88	130	55	50	1.522
Anchorage, Alaska	57	26	40	48	54	61	100	156	211	269	298	317	338	171	133	2.419
	58	26	24	31	44	85	93	118	139	164	216	242	487	137	104	2.246
	57–58	52	24	39	57	79	95	134	159	214	253	307	487	154	121	2.301
Phoenix, Ariz.	57	26	119	139	149	164	200	221	249	269	317	408	488	246	221	1.532
	58	23	95	109	126	135	164	202	219	236	253	346	410	200	186	1.561
	57–58	49	95	123	136	156	193	212	228	251	285	374	488	225	205	1.534
Los Angeles, Calif.	57	24	89	100	139	156	183	211	249	288	307	346	361	218	204	1.626
	58	21	111	139	164	179	193	228	244	261	279	298	296	213	214	1.360
	57–58	45	89	118	149	172	189	221	246	274	293	317	361	216	209	1.481
San Francisco, Calif.	57	26	42	44	47	51	55	67	81	89	100	139	211	80	69	1.580
	58	25	22	31	41	52	61	69	75	82	93	164	253	80	66	1.768
	57–58	51	22	38	45	50	57	68	77	85	98	152	253	80	68	1.665
Pasadena, Calif.	57	23	64	76	100	109	118	145	158	168	176	189	219	137	132	1.427
San Jose, Calif.	57	25	27	37	93	104	108	114	118	145	158	193	221	118	109	1.656
San Diego, Calif.	57	26	32	54	59	76	85	91	98	106	145	158	241	100	91	1.535
	58	23	45	49	58	63	66	70	85	100	118	193	233	93	81	1.627
	57–58	49	32	52	58	65	72	87	93	104	129	164	241	97	85	1.567
Burbank, Calif.	57	26	41	85	100	129	147	168	181	189	228	317	433	180	159	1.619
San Bernardino, Calif.	57	23	35	85	129	152	174	249	279	298	317	374	470	235	207	1.773
Fresno, Calif.	58	24	18	18	72	81	100	112	122	135	152	228	372	122	95	2.156
Oakland, Calif.	58	25	23	41	52	65	72	90	100	129	164	211	289	104	90	1.901
Sacramento, Calif.	58	25	11	16	37	57	61	72	85	174	193	249	403	112	77	2.775
Long Beach, Calif.	58	25	48	85	118	144	154	174	193	214	228	374	566	195	172	1.644
Richmond, Calif.	58	22	19	26	41	52	58	67	76	85	96	118	186	73	63	1.725
Stockton, Calif.	58	26	20	44	75	85	95	122	132	139	158	193	316	124	106	1.688
Honolulu, Hawaii	57	26	30	33	34	37	39	41	43	48	58	76	87	46	43	1.360
	58	23	30	31	41	44	48	55	61	68	75	85	123	58	53	1.466
	57–58	49	30	33	37	40	42	45	51	58	72	81	123	52	48	1.430
Las Vegas, Nev.	57	25	54	118	123	130	134	143	152	164	183	255	468	165	151	1.310
	58	22	70	72	100	114	123	134	147	164	216	269	639	173	138	1.601
	57–58	47	54	100	112	123	131	139	150	164	205	249	639	169	146	1.406
Portland, Ore.	57	26	32	39	44	61	68	81	100	118	134	164	315	98	80	1.804
	58	24	26	25	37	61	87	91	96	109	129	183	334	99	78	2.053
	57–58	50	26	34	44	61	72	88	97	114	132	179	334	99	79	1.883
Seattle, Wash.	57	25	41	52	61	85	104	114	123	139	156	193	446	124	105	1.661
Tacoma, Wash.	58	24	37	44	52	58	85	100	112	147	164	193	250	111	94	1.870

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WASTE DISPOSAL *without Air Pollution**

C. R. COMPTON, Chief Engineer and General Manager,
and **F. R. BOWERMAN**, Assistant Chief Engineer, Los Angeles County Sanitation Districts

Air pollution usually results from the direct discharge of gaseous and particulate wastes to the atmosphere; however, the indirect disposal of liquid and solid wastes can add materially to the burden of the atmosphere, if appropriate disposal processes are not applied. Disposal of liquid and solid wastes is often effected by persons not familiar with matters of air pollution and, as a consequence, techniques for disposal are sometimes employed which aggravate air pollution problems. Engineering experience and technical data are available to enable the selection of disposal methods commensurate with requirements for air pollution control.

Familiar examples of waste disposal procedures which use the atmosphere for disposal are in the burning of combustible materials, either in or outside of incinerators, and in the storage by open-ponding of petrochemical wastes, with resulting evaporative losses. Many parallel situations occur at homes, commercial houses, and industries, such that an accounting of all of the waste disposal procedures used in disposing of liquid and solid wastes would be beyond the scope of this paper; however, the disposal of liquid and solid wastes usually falls into several categories which may serve to exemplify the procedures which should be followed in other special cases.

Refuse Disposal

The most formidable problem in solid waste disposal currently facing municipalities both here and abroad is that of refuse disposal. Comprising garbage, rubbish, ashes, and a complex list of materials used and wasted by the householder, commerce, and industry, refuse is much the greatest quantity of solid waste which is subject to routine collection and disposal. Certain fractional components of refuse are salvaged as in the feeding of garbage to hogs, the separation of cans and bottles for reuse, the saving of paper and cardboard to serve as the raw material for the paperboard industry; such salvage operations represent but a small portion of the total refuse generated within a community. Some salvage operations are notoriously guilty of air pollution as evidenced by such practices as the open burning of car bodies to rid the steel bodies of paint and fabric prior to the reclaiming of the metal by melting and reuse. In some critical air pollution areas such burning has been prohibited and junked cars are hand-stripped of fabric and wiring before being baled for shipment to points of reuse. Suitable, completely enclosed, auto-burning furnaces have been installed in New York City, subsequent to the passage of a law forbidding open burning of auto bodies, in which electrostatic precipitators are used to bring the stack discharges within the prescribed limits. Similar installations have been made in other cities to minimize the air pollution from such salvage.

In Los Angeles, air pollution laws pertinent to the burning of tin cans for salvage, necessitated a complete reconstruction of the incinerator to embody two-chamber operation, as a means of eliminating illegal stack discharges. Additionally, the salvage company designed and built storage bins into which loads of cans and bottles could be dumped without releasing clouds of dust and ashes. The bins are equipped with large blowers to create a negative air pressure, the dust-laden air being cleaned with bag-filters. Many similar problems exist in the salvage of refuse; fortunately, most such problems are amenable to corrections as indicated, even though the solutions invariably require expensive construction and continuing costs for operation and maintenance.

Oft-reported alternatives, such as composting and destructive distillation, are yet in the development stage and cannot be considered as proved techniques for refuse disposal; however, neither composting nor destructive distillation would appear to pose air pollution problems, provided composting operations are always maintained in an aerobic zone of decomposting operations are always maintained in an aerobic zone of decomposition and gaseous products of combustion resulting from destructive distillation are subjected to temperatures sufficient to insure nearly complete oxidation.

The feeding of garbage to hogs as a means of salvaging some of the value in the wasted food products has produced air pollution problems for many years which, although not great in the sense of affecting large areas, are intense in the immediate area affected. Garbage feeding hog ranches have gradually been moved out of metropolitan areas because of the stench associated with the decaying garbage; recently, almost nation-wide changes in state laws have required the cooking of garbage to prevent disease transfer among the animals, resulting in a somewhat salutary effect on odors, but not sufficient to permit close proximity of hog feeding areas and residences without attendant odor nuisances.

Even the most efficient systems of refuse salvage cannot operate without the necessity to dispose of valueless or rejected material. In the United States there are currently practiced two principal systems of refuse disposal: Burial through sanitary landfilling or open dumping; and incineration—either within carefully designed and constructed incinerators, or in simple, single-celled incinerators, or open bonfires.

Incineration

Incineration of municipal refuse in large incinerators specifically designed for the task has a history of a little more than a half century; during that time there has been a gradual recognition of the necessity to control stack emissions to prevent pollution of the atmosphere. Earliest problems were largely associated with low-temperature burning of garbage or food wastes, a

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process which resulted in much odor. More recently, refuse has contained an abundance of dry, fibrous material such as paper and cardboard, lessening the problems of maintaining adequate temperatures; however, with the change toward more combustible material, there has developed problems of fly ash emission, including gross particles which settle rapidly within the neighborhood of the incinerator, and a myriad of miscroscopic particles which settle so slowly as to become virtually a constituent part of the atmosphere. Nothing much was done about such problems until about 1950 when an awakening of interest in refuse disposal caused several research groups to commence studies on the basic problems of incineration. Thousands of dollars spent in research, along with many millions of dollars spent in construction of new incinerators, have yielded somewhat less than spectacular results as far as over-all improvements are concerned; nevertheless, certain techniques have been developed which, if adopted, will lessen the amount of air pollutants discharged from municipal incinerators, thereby enabling them to become useful tools for refuse disposal.

The simplest way to reduce discharges of air pollutants from municipal incinerators has proved to be a lowering of incinerator grate loadings. A lower burning rate, with less use of undergrate air, results in quiescent burning which, in turn, reduces the amount of ash suspended above the grate to be discharged through flues and chimneys to the atmosphere. Although simple and direct, this proves to be a very expensive solution, since construction costs are proportional to the rate at which refuse can be burned. Another approach is to use secondary combustion chambers which act, in part, to settle the fly ash and which presumably insure a more complete combustion of gases. Secondary combustion chambers cannot appreciably reduce the amount of fine particulate matter discharged with combustion gases, since it is not feasible to build such chambers large enough that gases may be slowed to the low velocities required to settle the finer particles. A few simple tests have demonstrated that levels of turbulence are sufficiently high in secondary combustion chambers to provide very little effective separation of any but the largest fly ash particles.

To improve efficiencies of particulate removal, water sprays and water-bath entrapments have been used. Sprays alone have not proved of particular value, except to cool gases, thereby reducing velocities; however, sudden changes in the direction of gas travel by baffling, in connection with water baths to capture impinged particles have proved moderately successful. Still more efficient removals are found with the use of certain industrial-type water scrubbers, some of which involve both cyclonic separation and water entrapment. Another refinement, not yet installed on any of the very large municipal incinerators in the United States, is the electrostatic precipitator which would serve admirably to remove much of the particulate load, including even the finer particles. Disadvantages, besides cost, involve high maintenance and low efficiencies caused by the high temperatures of exhaust gases, 1800° to 2000° F, or alternative problems associated with handling a cooler flue gas, but one heavily laden with moisture from a spray chamber.

Today, the designer of a municipal incinerator is faced with the problem of deciding which of the several aforementioned systems is to be applied to the particular design at hand; his decision must be based upon relative costs which, in turn, may depend greatly upon the local criteria governing stack discharge. It is quite obvious that the more restrictive the local air pollution requirements, the greater will be the cost for building and operating incinerators. The effect that economics have upon the use of municipal incinerators is clearly demonstrated in Los Angeles County where of the nine minicipal incinerators which were operating in 1955, only four are yet operating; of those four, one is to be placed on an inactive basis within the year and two others further reduced in loading to meet air pollution control standards.

Sanitary Landfilling

Alternative to municipal incineration is the burial of refuse, usually in marshes, tidelands, canyons, or other such areas which may have little utility for other purposes. Sometimes such burial is effected without engineering controls, but the uncontrolled dumping of refuse often leads to vermin infestations and usually results in periodic fires. Very much preferred is the placement of refuse in compacted layers, with a cover of earth sufficient to prevent vermin infestation, to preclude fires, and to seal tightly the compacted refuse against the release of odors. Sanitary landfilling, as the latter practice is called, cannot always be used, since some cities may be so remote from suitable land for this purpose that even bulk hauling in large transfer trailers may not make landfilling economically feasible. In such cases, municipal incinerators may well be necessitated. Landfilling costs, however, are usually only about one quarter the cost of incineration; a fact which has greatly influenced refuse disposal practices in the United States in recent years. Sanitary landfilling does not contribute to air pollution if conducted in strict accordance with commonly accepted procedures.

Disposal of Industrial Wastes

Wastes from industry may be liquid, solid, or gaseous. Gases are customarily vented to the atmosphere, with or without pre-treatment, although scrubbing devices may be used to extract certain gaseous components for discharge to the sewer. The disposal of solid and liquid industrial wastes requires the use of land or water bodies for disposal, except for those disposal processes which involve incineration or distillation. Wastes from industry encompass on almost unlimited spectrum and contain such diverse constituents that it becomes necessary to tailor disposal procedures to each individual case. For some installations there are certain generally accepted procedures of waste disposal which may be invoked; however, most industrial operations produce several wastes of differing characteristics and it usually requires specialists in the field of industrial waste disposal to determine the most advantageous and least costly systems to be applied.

Liquid Industrial Wastes

Some liquid industrial wastes, for example, water from cooling processes, from rinsing cycles, and blowdown from steam generating equipment, may be discharged to stream channels or to percolation ponds without treatment. Conversely, acid or strong caustic solutions may be so damaging to receiving sewers or streams that elaborate and expensive pre-treatment must be given the wastes before disposal can be effected. Air pollution is of concern in the disposal of liquid industrial wastes in that conventional pre-treatment facilities often involve retention of the wastes in open sedimentation tanks. In other instances, air is blown through the industrial waste as a means of floating fine globules of oil or oxidizing some of the components of the waste. In such instances, the customary result is a transfer from the waste to the atmosphere of undesirable chemical constituents which result in local or general air pollution or both.

Liquid industrial wastes most likely to contribute to air pollution generally derive from the chemical or petro-chemical industries. Most inorganic solutions of acids or caustics used in metal-working processes are relatively inodorous and seldom present difficulties in disposal. Organic compounds, generally those associated with the refining of crude oil and specifically those involving phenolic and cresolic components, may prove to be sources of air pollution, unless pretreatment facilities are designed to prevent exhausting of the air which has come in contact with the waste liquors.

Such simple expedients as covering sedimentation tanks or avoiding the use of open pond areas are sometimes all that are required.

As a case in point, until recent years, it has been common practice to separate the small fractions of floatable oil which remain in connate brines from producing oil wells by temporarily storing the oil brine in large, shallow ponds. Several days' detention would permit most of the floatable oil to rise to the surface of the ponds where it could be skimmed and reclaimed, and the decanted brine discharged to the sewer free from the otherwise excessive amounts of floatable oil which would prove deleterious to sewage treatment functions. An undesirable result was the exposure to the atmosphere of the floating oil and the ready evaporation of the lighter fractions to the atmosphere. To obviate this, some oil fields in Los Angeles County have abandoned the use of ponds, substituting instead a simple air-pressure flotation device which achieves the same effect in the span of about a half hours' detention with an almost insignificant exposure of crude oil to the atmosphere.

Another source of air pollution from the liquid industrial wastes which derive from oil refining is in the disposal of "tank bottoms" which are residual materials which settle to the bottom of storage tanks. Such residue cannot be discharged to sewers, nor can it be dumped in water bodies such as rivers, lakes, or the ocean. A common practice is to remove the tank bottoms by pumping into vacuum tank trucks for haul to land disposal sites. Such sites must be carefully chosen, since they must not be near homes less they create local problems of air pollution and must be so situated as to be free from ground water pollution hazards. This latter requirement is so restrictive that, for example, in Los Angeles County, no dumping sites are available where tank bottoms or other potential pollutional wastes may be legally discharged. The nearest such sites are in neighboring counties in rock formations which preclude continuity with ground waters; truck hauls of from 50 to 60 miles are not uncommon. Where tank bottoms are dumped for disposal, serious local problems of odor may be minimized by using trenches or pits which are relatively deep, thereby minimizing the surface exposure. Some loss of volatile hydrocarbons seems inevitable from such disposal techniques, although the incorporation of residue materials into sanitary landfills may minimize release to the atmosphere of volatile substances; such disposal has not been practiced, since it is not known to what extent hazards of fire in landfills are increased through the incorporation of petro-chemical residues.

A liquid industrial waste common to the refining of crude oil into gasolines and other fractions is a caustic by-product containing cresolic compounds. Some salvage of these cresols has been effected; however, as is common with most salvage operations, some portion of the product must be wasted. Caustic solutions containing cresols cannot be discharged indiscriminantly to sewers, since the odor-producing properties are so great that air pollution problems are created for as much as a mile or more along the receiving sewer because of the release of odors through vents in manholes. Some success has resulted from choosing sewers for disposal which traverse areas not yet developed residentially; however, in a metropolis such areas are uncommon. Rapid dilution in relatively large sewage flows is perhaps the least offensive and most economical means of disposing of such concentrated odor-producing substances; alternative disposal to the land necessitates isolation, requiring long hauls in vacuum tank trucks.

Many examples paralleling those previously described are found in industrial communities; the solutions are not always obvious, but, in almost all instances, satisfactory disposal systems can be developed which will prevent the pollution of the atmosphere.

Solid Industrial Wastes

Much of the solid waste from industry is similar to the combustible rubbish derived from households and commercial houses; to wit, paper, cardboard, and other such cellulosic materials; these may be buried or burned as previously described. Somewhat more perplexing are solid wastes, usually dusts, which are associated with electrostatic precipitation, bag filtration, or other such dry removal of fine particles from exhaust stacks. Whereas, in former years the atmosphere was used for disposal of such particulate matter, present-day air pollution controls require their separation from exhaust gases, thereby creating a new waste material disposal problem.

Fly ash from incinerators and steam generating plants has been used as an admixture in concrete with some success, although such is not practiced widely. The presence of significant amount of trace elements in fly ash has caused some research looking toward the utilization of fly ash as an admixture for fertilizers and soil amendments. No major uses of fly ash have yet resulted from such studies and in almost all instances fly ash, along with other collected particles from widely varying stack discharges, is disposed of through burying. At this point, one must be careful that the solution to an air pollution problem does not result in a water pollution hazard, since most of the dusts collected by air pollution control devices are, to a degree, soluble in water and are, therefore, suspect when placed in the ground for disposal. Studies on the leaching from ash dumps reveal the serious probability that ground waters will be materially polluted if ash is so dumped that water percolates through the deposit, carrying dissolved chemicals into the ground waters below.

Magnesium filings from industries producing magnesium parts for aircraft pose a serious hazard which indirectly relates to air pollution in that rapid oxidation of the fine metal particles may result in auto-ignition and create fire. Customary handling of waste magnesium filings is done in drums filled with water or oil so that oxygen cannot be supplied to the fine metal chips through contact with the atmosphere. Depositing such drums in sanitary landfills may result in eventual fires if the liquid bath is permitted to escape from the drum. A technique which seems desirable in the handling of such filings is to mix them with copious quantities of earth such that the individual filings are well separated; through such handling, no concentration of filings is permitted which allows the development of sufficient heat to ignite the refuse in the surrounding fill.

Solid wastes originating from industrial processes are seldom air pollutation problems in themselves, but may contribute to air pollution if improperly incinerated. Burying through sanitary landfilling is an appropriate waste disposal procedure for solid industrial wastes, provided landfilling sites may be obtained where water-soluble wastes will not contribute to ground water pollution. It is common practice among industries to reuse considerable fractions of solid waste material as in the salvage of cellulosic by-products and in the recovery of metal, plastic, or other wastes for their intrinsic value.

Conclusions

Waste disposal may in almost all instances be consummated without placing an undue burden on the atmosphere; however, the accomplishment of that end results from careful planning and is seldom accidental. Awareness of the need for minimizing air pollutants has not always characterized the activities of those saddled with the responsibilities for effecting waste disposal, but an awakening of interest is evidenced and fewer bad choices will be made as engineers become more familiar with air pollution relationships. Air pollution control officers may quicken the education process by serving as catalysts between the needs of the waste producer and the designer and operator of the waste disposal facility. It would appear that many of the questions relative to air pollution from waste disposal could be answered if each of those entrusted

(*Continued on page 95*)

Proportional Sampling System for the Collection of an Integrated AUTO EXHAUST GAS SAMPLE*

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Summary

The proportional sampling system was developed for the purpose of obtaining an integrated auto exhaust gas sample. The system was designed to accumulate continuously a constant percentage of the discharge gas from a vehicle under road operating conditions. The sampling rate varies simultaneously with the exhaust gas flow rate. This is accomplished by an electronic system consisting essentially of a strain gage pressure transducer, voltage amplifier and a power amplifier. The latter operates a servovalve. The control signal to the system is obtained by the use of a viscous flowmeter which meters the air delivered to the carburetor system of a vehicle.

An evacuated receiving tank accumulates the metered portion of the total exhaust gas emitted while a vehicle is operated. The collected sample is subsequently analyzed and the total quantity of exhaust gas components emitted from a vehicle during a test run is readily determined.

Introduction

The exhaust gas emissions are determined from the product of the concentration of each component and the volume of gas discharged. Either or both of these factors are continually fluctuating over wide ranges during road operation of a vehicle. These conditions have heretofore made it a difficult task to combine the two factors in the proper proportion. This was primarily due to limitations of known sampling and analytical techniques. Therefore, an indirect, complicated and tedious procedure had to be used. This necessitated classifying the engine operating conditions into four categories based on the throttle position and the manifold vacuum. The conditions were idle, acceleration, cruise and deceleration. Their relationship to each other was derived from traffic and driving pattern surveys. The information thus obtained was used to arrive at a synthetic set of driving conditions to facilitate the sampling and analytical procedures necessary for the determination of the emission of exhaust gas components. The following values were necessary for each operating condition:

1. Average exhaust gas flow rate.
2. Percent of total driving time.
3. Average concentration of each exhaust gas component.

Because it is desirable to express the quantity of each exhaust gas component on a weight percent of the supplied fuel basis, it was also necessary to know the average fuel consumption of each operating condition. These values were proportioned to arrive at a total emission value. Since the evaluation procedure was carried out on a piecemeal basis, a large number of operating variables had to be examined so that the test conditions established would be representative of driving conditions in a given area. The accuracy of the calculated emission values depended on the stability and validity of all data used. It is unlikely that this approach was capable of adequately taking into consideration all of the transient operating conditions that occurred while a vehicle was being operated. It is for this reason that an auto exhaust gas proportional sampling system was developed.

Considerations and Feasibility

The idea for the proportional sampling system for obtaining an integrated exhaust gas sample was conceived several years ago. It was not feasible at the time because of the lack of an adequate variable metering valve. It was realized that if a system could be designed so that a constant percentage of the total exhaust gas could be accumulated during the operation of a vehicle, it would then be a simple matter to relate the volume collected and the subsequent analysis of the sample to the total volume discharged. Limitations would not be imposed on the number of analyses performed or the analytical techniques employed. The emission rate of any specific exhaust gas component could also be related to the total weight of supplied fuel by merely metering or calculating the fuel consumed for a given test run. The exhaust gas flow rates fluctuate, at times, from instant to instant. It is necessary that the metering control unit not only respond instantaneously to these fluctuations but do so without any overshooting.

The emission rate of total hydrocarbons, on the basis of the quantity of fuel supplied to the engine, is by far the greatest during decelerating operation conditions.[1] These are low volume discharge operating conditions. To obtain a representative exhaust gas sample, the system must incorporate a high degree of linearity and stability throughout the entire sampling rate range. In addition, the system must incorporate variable sampling range settings to provide for test runs having an elapsed operating time from one to three hours.

Taking into consideration the operating variables of a vehicle, it was felt that a continuous proportional sampling system could be designed with an overall accuracy of greater than 90 percent for a test run.

System Operation

As shown in Fig. 1, the auto exhaust gas proportional sampling system consists of the following interrelated components:

1. Viscous flowmeter.
2. Strain gage pressure transducer assembly.
3. Pressure transducer control units.
4. Transistor amplifier.
5. Transistor constant current amplifier.
6. Sampling servovalve.
7. Exhaust gas sample accumulator tank.

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The air flow rate into the carburetor of a vehicle is considered to vary simultaneously with the exhaust gas flow rate. Although the flow rates are not identical, the ratio of wet exhaust gas to air consumed by an engine is rather constant; there is only a variation of five percent between air-fuel ratio changes between 12:1 and 14:1. This relationship is shown in Fig. 2. Advantage is taken of these relationships by utilizing a viscous flowmeter[2] in place of the standard air filter.

Laminar flow is a characteristic of the viscous flowmeter; the pressure drop across the matrix section is proportional to the air flow. The variations of the pressure differential control the sampling rate. The pressure differential is converted into an electrical signal by the transducer. This signal is amplified to a level adequate for the positioning of the servovalve. This valve permits a metered portion of the exhaust gas to be drawn into the accumulator tank. To protect the valve, the portion of the exhaust gas passes through a condensate trap and primary[3] and secondary[4] filters before entering a rotameter and servovalve. The installation of the proportional sampler in a test vehicle is shown in Fig. 3.

Described in order, beginning with the flow-sensing element and ending with the servovalve and vacuum tank, these components are now discussed in greater detail.

Viscous Flowmeter

The viscous flowmeter was constructed within a standard air-filter housing and designed so that the air flow characteristics entering the carburetor would be essentially unchanged. This unit operates within the same pressure range as the standard air filter (Fig. 4), and thus does not alter engine operating conditions.

The viscous flowmeter was calibrated by means of Venturi orifices, an air chamber, and an adjustable auxiliary air blower. Acutal test data for the Ford "6" unit are plotted in Fig. 5. Cleaning has been standardized at approximately every 500 miles.

Pressure Transducer

The pressure transducer assembly consists of two low-level Statham pressure transducers[5] mounted in mechanical opposition so as to cancel out the appreciable effects of road vibrations on the mass of the diaphragm. This is described in more detail later. These transducers are electro-mechanical devices each consisting of four unbonded strain gage elements which "transduce minute displacements to proportional resistance changes."[6] The elements are mounted on an armature which is coupled to a diaphragm across which the

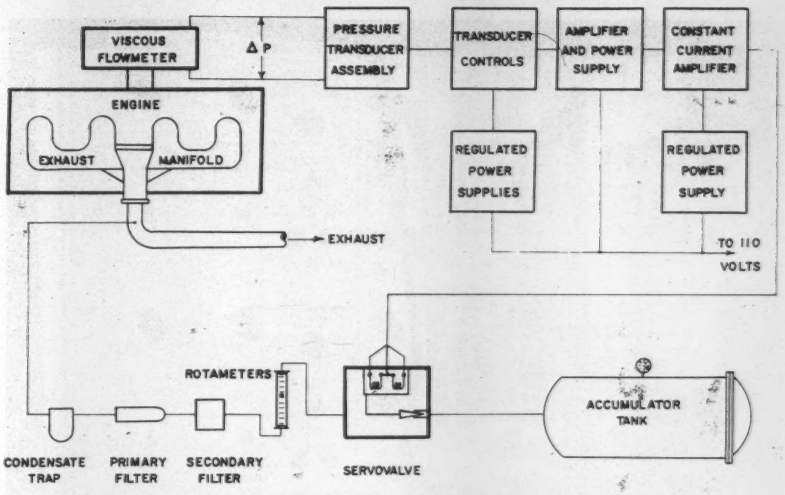


Fig. 1. Arrangement of proportional sampling system components.

measured differential pressure is applied; one side is upstream from the viscous flow element and the other is downstream. Since the four elements of each transducer are connected as a Wheatstone bridge circuit, it converts mechanical energy, in the form of the pressure differential, into a control signal voltage. Non-linearity and hysteresis are of negligible magnitude.

Two six-foot connecting tubes having an inside diameter of 0.25 in. are used to connect the transducer assembly to the viscous flowmeter. Calculated attenuation and lag time of a sinusoidal pressure singal are negligible[7] over the length of this transmission line terminated in the transducer internal volume.

Control Unit

The control unit is of the conventional type for use with strain gage transducers. It consists of zero adjusting and calibrating circuits. Since the

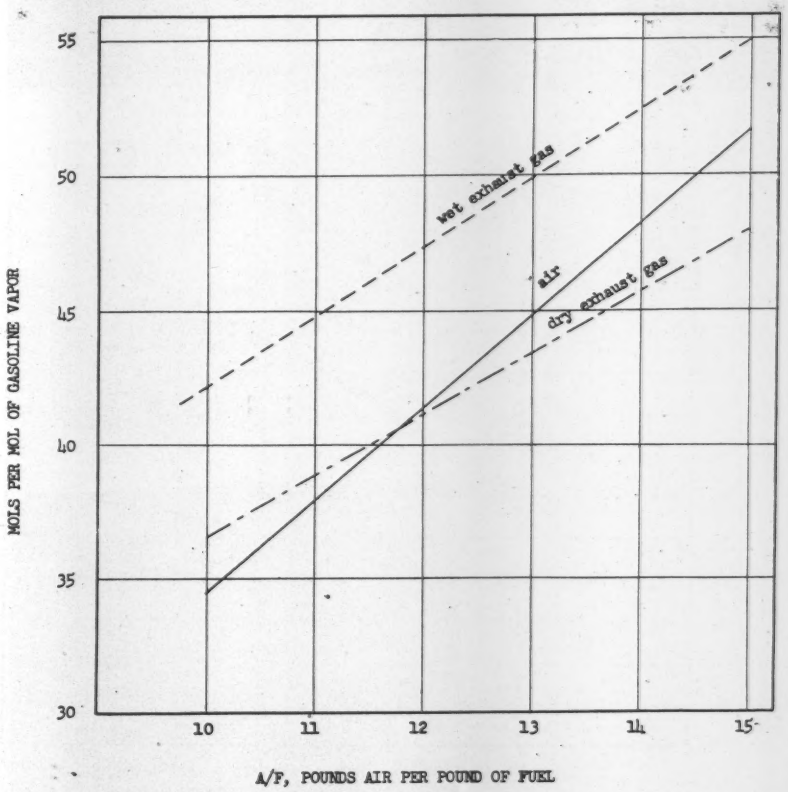


Fig. 2. Relationship of air flow to exhaust gas flow.

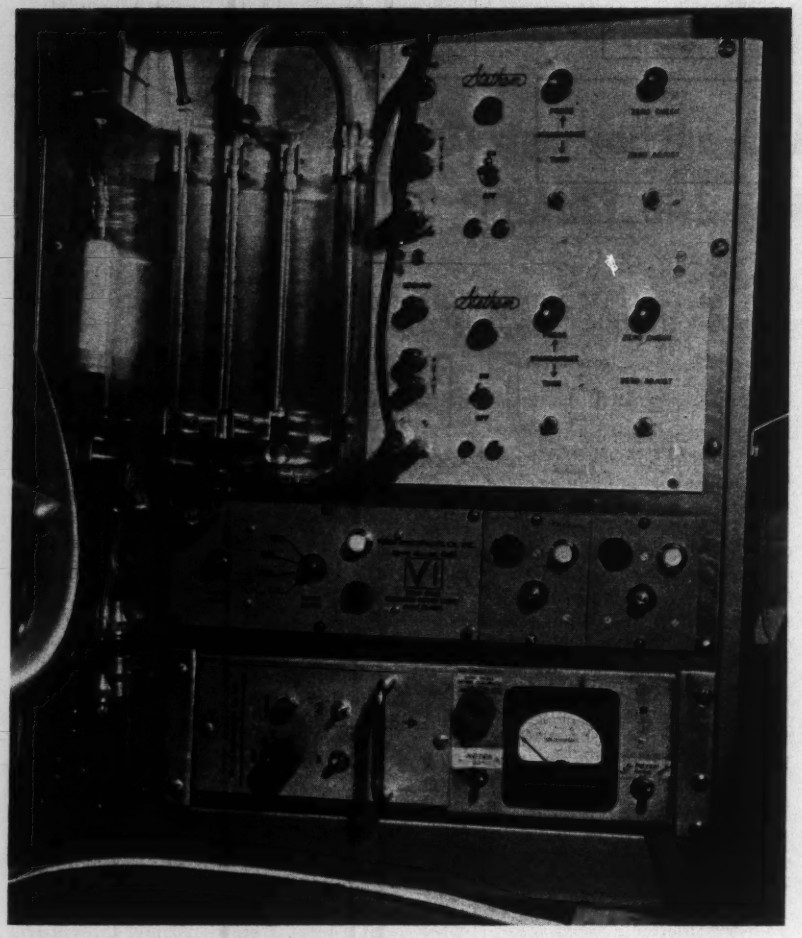


Fig. 3. Installation of the proportional sampler in a test vehicle.

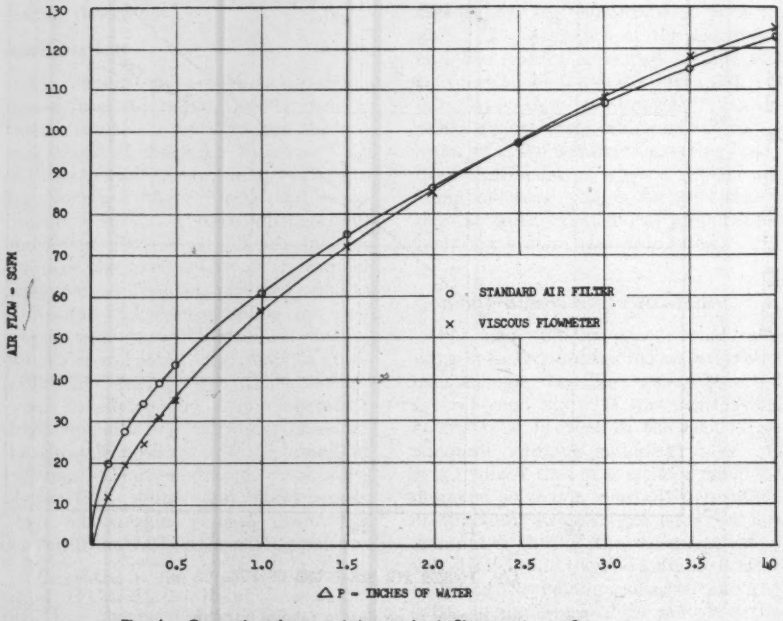


Fig. 4. Operating characteristics—std. air filter vs viscous flow meter.

system required better stability over extended periods than was obtainable with lightly loaded lead acid batteries, solid state stabilized power supplies were used instead.[8] These have line regulations of better than 0.1% and negligible temperature drift.

Transistor Amplifiers

The first transistor amplifier unit[9] increases the electrical output of the control box by a factor of 100, 200 or 500 depending upon the pressure range of the individual viscous flowmeter being used and the output settings of the pressure transducer power supplies. This amplifier unit is a differential D-C amplifier incorporating a high degree of linearity, stability, and reliability. It operates directly from a 110-volt inverter. Its output operates a second transistor differential amplifier unit[10] which is a constant current device for furnishing the power to position the servovalve. The output impedance is many times higher in magnitude than the coil resistances of the servovalve. This minimizes drift caused by changes in coil resistance due to variations of temperature. The source of power for this amplifier is a solid state rectifier regulator.[11]

Even though the amplifier system is constructed to minimize effects of temperature on stability, this was not found adequate for the relatively rapid temperature variations encountered in the interior of a vehicle. This was overcome by insulating the amplifier module and thermostating it to within ±1°F of a preset value. This value is set at approximately 15° above ambient temperature. Even temperature distribution is maintained in this module by a small fan blowing across the heating lamp.

Continuous monitoring of the output circuit is provided by a 0 to 1 milliampere meter in the output circuit. Its deflection is proportional to sample and exhaust flow rates.

Servovalve

The desired overall linearity of the system is obtained by the last major component as previously shown on the simplified flow diagram. This is the servovalve[12] which is located in the sampling line between the exhaust manifold and the evacuated tank. It must take the electrical output from the second amplifier unit and convert it to a valve opening corresponding to the correct flow over the sampling range of 0 to 2 liters per minute.

This servovalve consists of a torque motor and a sampling needle valve housed in a vacuum-tight case. A photograph is shown in Fig. 6. The

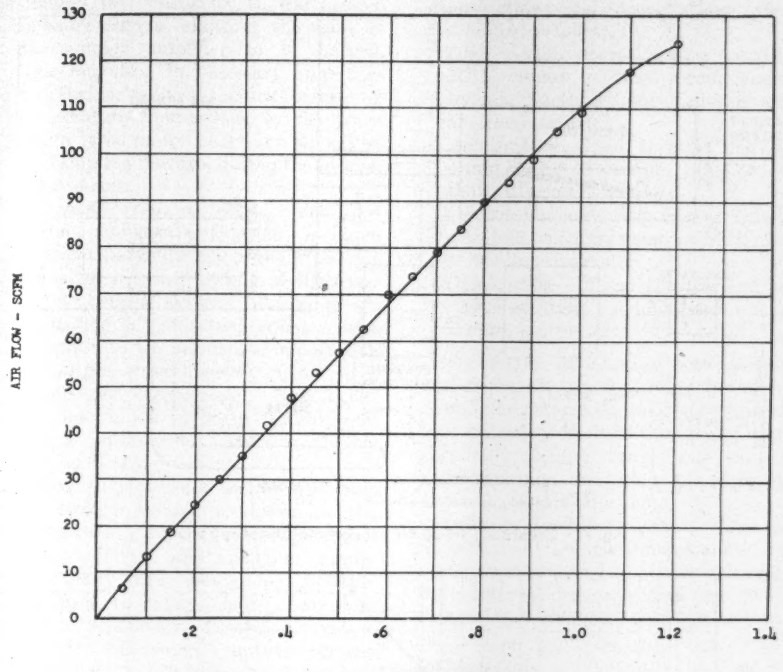


Fig. 5. Viscous air flow meter calibration curve.

torque motor is designed to transform a few watts of differential output from the drive amplifier into a proportional mechanical motion. It utilizes two coils operating in push-pull in a highly efficient or "tight" balanced magnetic circuit. The magnetic circuit has a hysteresis of two percent and its flat armature is supported by frictionless flexure bearings which contribute to its good repeatability characteristics over a long period of time. The full stroke of the valve is approximately 0.01 inch. The mechanical displacement positions the needle valve to meter a constant percentage of the total exhaust gas. This is accomplished by maintaining its operation always within the critical region of flow.

Before each run the valve seat and plunger are cleaned with a small brush and acetone.

Accumulator Tank

Critical flow for the servovalve is maintained by an evacuated 2.71 cubic foot exhaust gas accumulator tank located in the trunk of the vehicle. Depending on the length of the test run, sampling rate is preset to utilize approximately half of the tank capacity.

The tank is a porcelain-lined metal cylinder which houses a collapsible Saran plastic bag. This bag is sealed from leakage into the interior of the tank and connected to a nipple at one end of the tank. It is, in effect, a gas container within a gas container. A porous hose is inserted coaxially to assure uniform evacuation of the bag. The tank is flanged and gasketed at one end for the convenience of installing the bag and for ease of periodic cleaning. Adequate nipples are provided for connecting lines to the tank, bag, and vacuum gage.

Since the pressure in the tank is less than atmospheric at the termination of a test run (approximately one half of an atmosphere) air is allowed to enter and expand the bag within the tank until atmospheric pressure is attained. Depending on the disposition of the sample, additional air can be forced into the bag at controlled rates while the undiluted sample is expelled from the tank through analytical instruments, condensation or absorption trains, etc., for any desired analysis. This technique provides a simple means of transferring the accumulated exhaust gas sample from the tank.

Calibration

Calibration of the proportional sampling system was accomplished by passing known flow rates of air through the viscous flowmeter and metering the corresponding sample flow rates. The calibration setup is shown in Fig. 7.

The viscous flowmeter was installed in a 27 cubic foot air chamber in such a manner that any air entering the chamber had to pass through the viscous flowmeter before being discharged. The air flow into the chamber was metered by calibrated Venturi orifices having throat diameters of 0.719, 1.800 and 2.000 inches. They were mounted on a 50-gallon surge tank. While one Venturi orifice was being used, the other two were plugged. This was a convenient way to change from one orifice

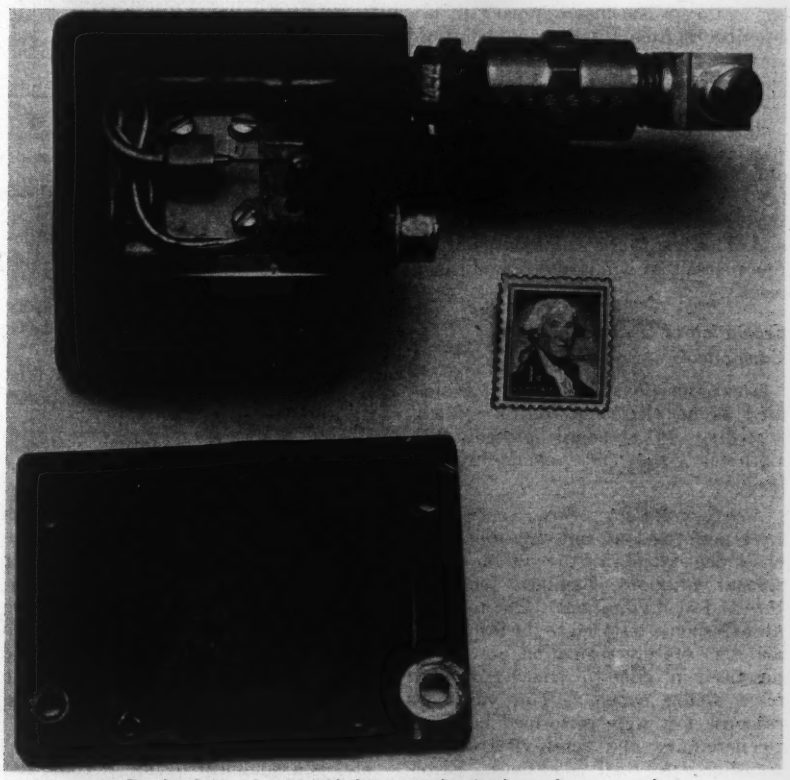


Fig. 6. Servovalve unit with the vacuum housing base plate removed.

to another, as necessary, to cover the wide range of flow rate settings for calibrating the system. The air entered the calibration setup through one of the orifices, through the surge tank and into the air chamber. The air was then discharged from the chamber by passing through the viscous flowmeter and air blower in a continuous cycle. A damper, located at the inlet of the blower, was used to control the air flow rate. Inclined tube draft gages were used to convert the pressure differential across the orifice to the corresponding air flow rates in terms of cubic feet per minute (cfm).

The proportional sampling system was adapted to the calibration setup. A rotameter was connected to the inlet of the servovalve to meter the sampling rate; a vacuum source was connected to the outlet of the servovalve. For each of several system gain settings, air was passed through the viscous flowmeter at various rates; the corresponding sampling rates were indicated by the rotameter. By plotting the corresponding flow rates vs. sampling rates, a family of curves was drawn. Figure 8 shows two of the calibration curves for the proportional sampling system.

Methods of Evaluation

After calibration, two approaches were used to evaluate the proportional sampler system as to its practical application. The first approach to be described is from an electronic point of view and the second is from an analytical point of view. Where road testing was necessary, the complete system was installed in a 1954 Ford "6" with standard transmission. Test data obtained by the two methods have been valuable in properly adapting the system to its road environments and in leading to the simplest operating procedures that will insure reproducible results.

Evaluation of Electronic Control Components

The proportional sampler was evaluated as an electronic control system according to standard procedures.[13] Both steady-state and dynamic-response tests were run.

Steady-State Tests. Steady-state tests were performed at constant inputs to check the stability of the system under normal variations of ambient temperature and road vibrations. The temperature response tests led to the insulation and temperature regulation previously described in order to reduce zero drift to a usable value. The vibration response test were performed in order to determine the sensitivity of the transducer to road conditions. Error from this source was found to cause as much as 60 percent increase in the deceleration phase volume collected and therefore necessitated correction. A capacitance large enough to adequately reduce this error signal would have made the instrument nonresponsive to the rapid transient changes in air flow rate by lengthening the overall response time.

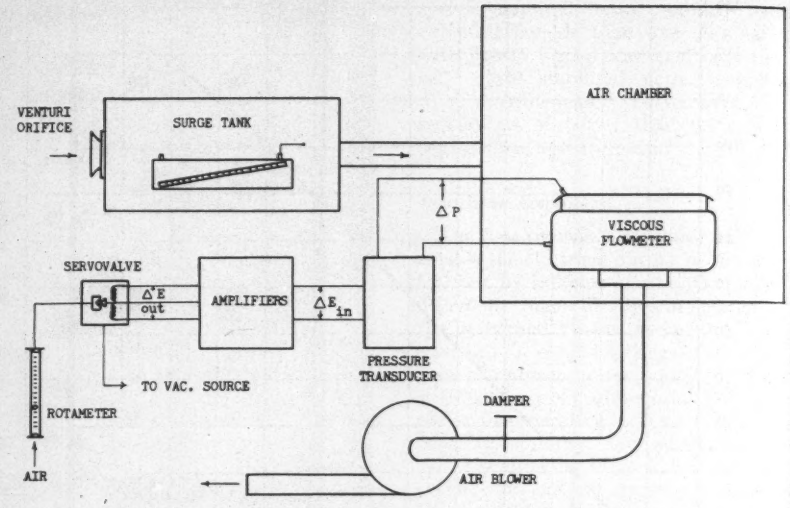


Fig. 7. Calibration set-up for proportional sampling system.

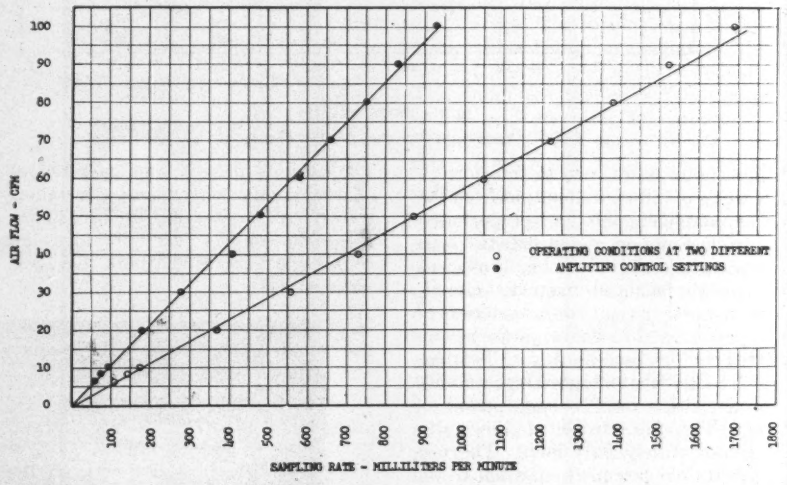


Fig. 8. Proportional sampling system calibration curves.

Various shock mounting methods were tried and not found capable of adequately isolating the pressure transducer from road vibrations. Various other solutions were investigated, one of which was a hot-wire anemometer as the airflow sensing transducer. Accuracy of such a device would not be influenced by changes in temperature of the air stream and thus it would have the same advantage of the radioactive airflow meter[14] developed by the Ford Motor Company.

However, since the hot-wire anemometer is a nonlinear device, it could not be utilized even though its response time can be made to follow fluctuations as rapidly as 10 per second.[15] Recently a nonlinear correcting circuit was developed[16] for use with hot-wire anemometers which delivers a voltage directly proportional to the instantaneous air velocity. It employs a vacuum tube control amplifier, drift correction amplifier, and linearizer. Further evaluation of adapting this device for measuring automotive engine airflow rates might be useful.

Because of its simplicity of installation and its ease of maintenance, it was desirable to retain the viscous-element-low-level pressure transducer method. A solution was worked out and is in current use. It consists of rigidly mounting two identical transducers back to back with pressure inputs in parallel and electrical outputs in series. By placing the two transducers mechanically in opposition in the vertical plane, the effects of road vibrations cancel out. This arrangement also

doubles the sensitivity to the desired pressure signals allowing the gain of the voltage amplifier to be halved. This reduction in necessary amplification further reduced the drift caused by temperature fluctuations to the point where it is rarely necessary to adjust the sampling flowrate during the process of a test run.

Dynamic-response Tests. The dynamic response evaluation included transient and frequency response testing. Transient response testing of the overall electronics system was done by connecting a calibrated square wave generator to the input and monitoring the output waveshape by means of a cathode-ray oscilloscope. Rise time* was determined to be in the order of several milliseconds with negligible overshooting and sag.

Frequency response testing was done in a similar manner to determine the response to a sinusoidal voltage signal at low, medium and maximum inputs from many times below the resonant frequency to many times above the resonant frequency. Electrical response characteristics were found to surpass the manufacturer's mechanical response characteristics of the torque motor loaded with the linkage arm and valve plunger.

For the analytical evaluation of the complete system, it was installed in the test vehicle which was operated over a preselected 28.7 mile route requiring 60 to 70 minutes driving time.

Analytical Evaluation of Overall System

The proportional sampling system continuously samples and accumulates the combustion products in the exhaust gas with respect to time, concentration and volume discharge at any given instant and/or for the duration of the test run of a vehicle. Since an infinite number of test conditions can be based on a combination of these variables, it was decided to incorporate all of them during the road evaluation testing program.

Sampling Conditions. The engine operating conditions were grouped and isolated into four broad categories with the idea in mind that the sum of the quantities of the exhaust gas effluents emitted, from each of the four categories, should be of the same magnitude as the one sample collected without employing the isolation procedure. The ratio of the sampling rate to the exhaust gas flow rate, however, was to be maintained at a constant value for all of the individual tests. The categories were based on a combination of throttle position, either open or closed, and manifold vacuum values. The categories are referred to as idle, acceleration, cruise and deceleration; they are defined as follows:

Idle—Engine operating at a speed in RPM equal to that recommended by manufacturer's specifications and at closed throttle.

Acceleration—Open throttle and an intake manifold vacuum value of less than 12 inches of mercury.

Cruise—Open throttle and an intake manifold vacuum value of 12 inches of mercury or greater.

Deceleration—Closed throttle and an intake manifold vacuum greater than at idle conditions.

To clearly differentiate between idle and deceleration and to allow for slight manifold vacuum fluctuations while at idle, the lower limit of the deceleration manifold vacuum range was set at approximately one inch of mercury above the normal idle value.

Isolation Sampling Control. The interruption of the continuous sampling system was required to obtain a sample for each of the specified operating categories. This was accomplished by an isolation sampling control arrangement shown schematically in Fig. 9. Two solenoid valves, connected in parallel, were installed in the sampling train—one was located at the proximity of the discharge manifold and the other was close-coupled to the servovalve housing. The simultaneous opening and closing of these valves was controlled by two microswitches connected in series; one microswitch was closed by the positioning of the throttle and the other was closed when the predetermined intake manifold vacuum range and throttle position, were satisfied, the solenoid valves opened and sampling commenced. The servovalve controlled the sampling rate until either or both of the microswitches were opened by a change in engine operating conditions. It is to be noted that the isolation sampling control arrangement in no way affected the positioning of the servovalve at anytime but only limited the sampling of the exhaust gas at the predetermined conditions.

The technique used to operate the microswitch, when the manifold vacuum valve was in the preset range, was to employ a strain gage pressure transducer[17] and a recorder.[18] The transducer was connected to the intake manifold vacuum source with tubing. The electrical output signal was fed to the recorder for the purpose of positioning a cam attachment for operating the microswitch.

The solenoid valves served two purposes; the one close-coupled to the servovalve limited the sampling of the exhaust gas to the preselected engine operating conditions. The other one isolated the collection train from the exhaust system when the sampling was interrupted, thus preventing contamination of the sample due to pressure pulsations in the exhaust system during this period.

To obtain a relationship between the quantity of combustion products emitted in the exhaust gas for each sampling condition of idle, acceleration, cruise, deceleration and the continuous (integrated), the following average values for each test run had to be determined:

1. Sampling time.
2. Exhaust gas discharge rate.
3. Concentration of exhaust gas components.

The above values, for the isolation sampling control procedures, were proportioned to arrive at a synthetic integrated value for the quantity of combustion products emitted. The magni-

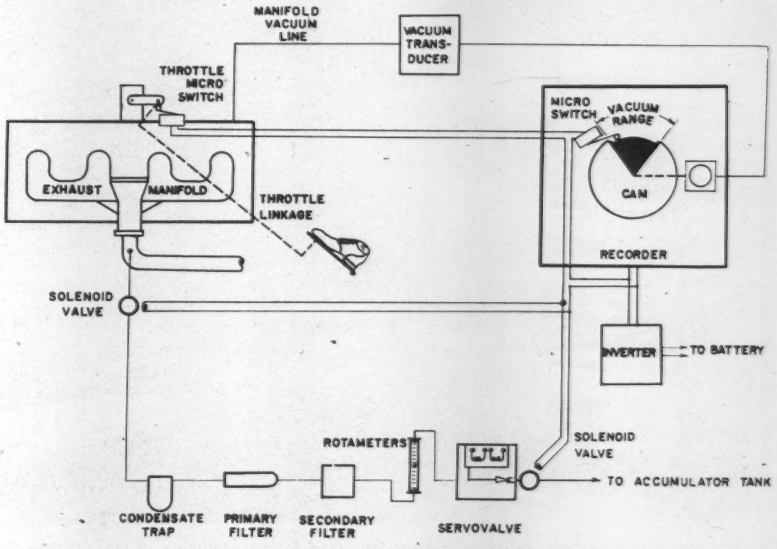


Fig. 9. Isolation sampling control arrangement.

* Rise time is defined as the time required for the amplitude to rise from 10 percent to 90 percent of full value.

tude of these values was used to compare with actual integrated values obtained with the proportional sampling system (without the interruption of the sampling procedure).

Sampling Time. An automatic timing device,[19] consisting of five individual timers, was incorporated into the isolation sampling control circuit. It accumulated, in minutes and tenths of minutes, the time spent in each of the engine operating test categories and also the total operating time of the vehicle per test run. Figure 10 shows a schematic sketch of the installation. With the exception of the total timer, each of the timers was energized when the predetermined manifold range and throttle position conditions were satisfied for the respective engine operating conditions of idle, acceleration, cruise and deceleration.

Exhaust Gas Discharge Rate. A series of test runs were made on the 28.7-mile route for each of the sampling conditions. The instrument calibration procedures were consistent in that the sampling ratio of 18 ml per cubic foot of exhaust gas discharge was maintained. At the termination of each test run, the accumulator tank pressure, the temperature of the collected gas and the sampling time were noted. Knowing the capacity of the accumulator tank, the average exhaust gas discharge rate, standard cubic feet per minute (scfm), was readily determined as follows:

$$\frac{P_1 - P_2}{P_1} \times \frac{V_t}{M} \times \frac{T_1}{T_2} \times \frac{1}{18} = Scfm$$

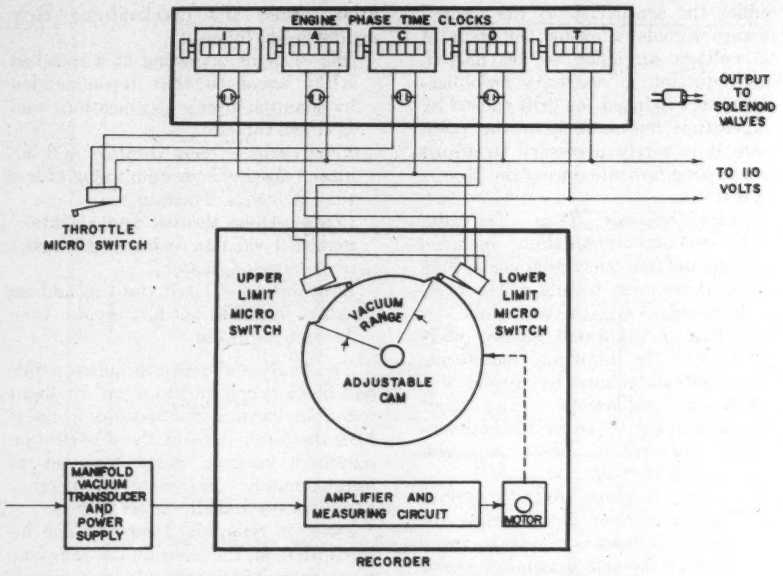


Fig. 10. Automatic timing and engine phase selecting circuit.

P_1 = initial accumulator tank pressure, inches of mercury vacuum

P_2 = final accumulator tank pressure, inches of mercury vacuum

V_t = capacity of accumulator tank, milliliters

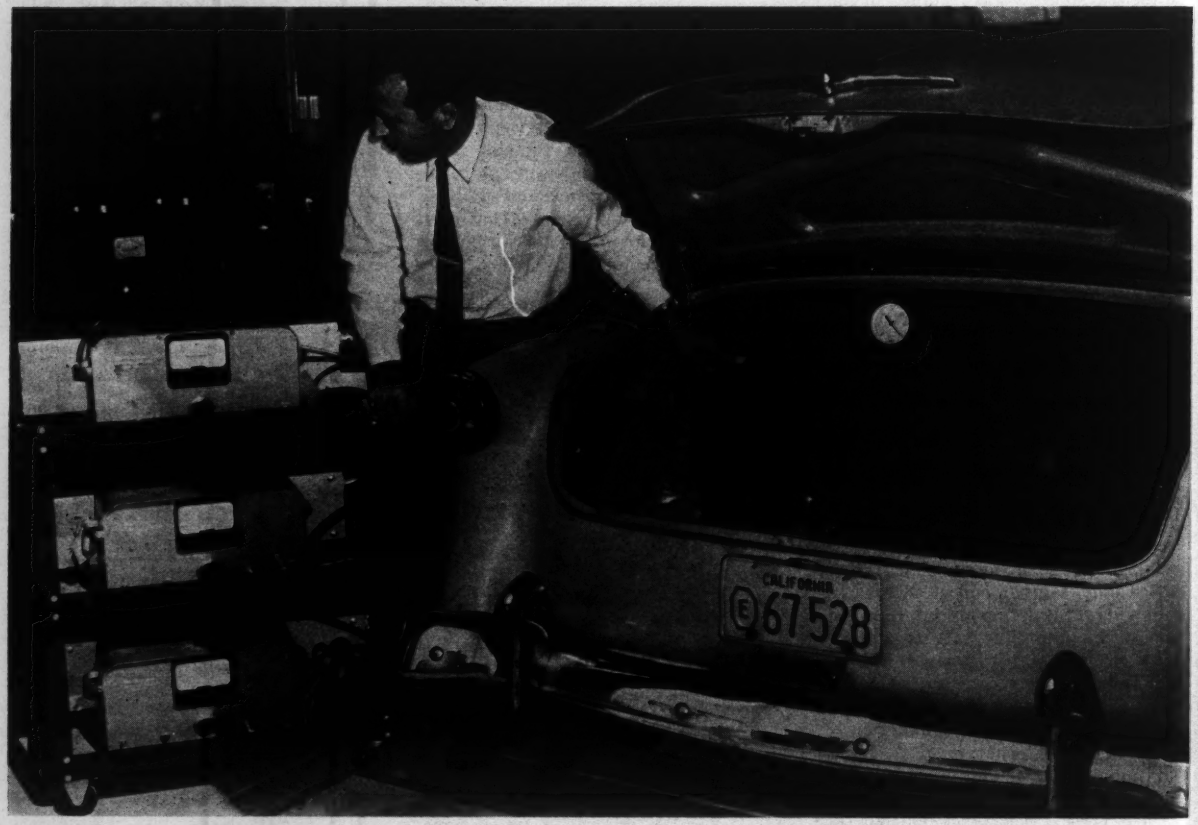


Fig. 11. Accumulated exhaust gas sample being analyzed for concentrations of total hydrocarbons (hexane equivalents), carbon dioxide and carbon monoxide.

M = sampling time, minutes
T_1 = 520°F Absolute
T_2 = 460°F + sampled gas temperature in °F.

The capacity of the accumulator tank used for collecting the exhaust gases at the specified operating conditions of cruise and acceleration as well as the continuous sampling procedure (integrated sample) was 2.71 cubic feet. The total exhaust volume emitted at idle and deceleration operating conditions is relatively low. During these operating conditions a 4300 ml accumulator flask was used. This necessitated a change in the displacement procedure for introducing the sample into the analytical instruments. An acidified sodium sulfate (Na_2SO_4) salt solution was used as the displacement medium.

Sample Analysis. The accumulated exhaust gas sample was analyzed by non-dispersive infrared analyzers for the following components at the termination of each test run:

Hydrocarbons, hexane equivalents.
Carbon dioxide.
Carbon monoxide.

Figure 11 shows these analyses being performed. In addition, several integrated samples were analyzed for oxides of nitrogen by the phenoldisulfonic acid method.

Test Results

A summary of the test results for each operating category of idle, acceleration, cruise and deceleration is shown in Table I; the results of the individual test runs are shown in Tables II, III, IV and V. Table VI shows the results of the test runs made without interrupting the sampling procedure. During the latter tests, the distribution of the time spent in each operating category was recorded. The average values are summarized below:

Operating Condition	% of Total Operating Time
Idle	19.9
Acceleration	21.1
Cruise	35.2
Deceleration	23.8

These ratios were used as a common basis for comparing the actual integrated test results with the calculated or synthetically integrated data. The calculations were based on the proportionate average values for exhaust gas flow rates, sampling time and concentrations of combustion products in the exhaust gas. Table VII shows this comparison.

Taking into consideration the uncontrollable variations in daily driving, such as driver habits, traffic flow, etc., during the 22 test runs, there is good agreement between the values given in Table VII.

Table I—Summary of Test Runs Using Isolation Sampling Procedure

Operating Conditions	Exhaust Discharge, scfm	H-C, ppm	CO_2, %	CO, %
Idle	6.2	780	9.9	2.9
Acceleration	62.2	350	9.9	4.3
Cruise	33.4	350	10.6	3.8
Deceleration	6.9	3100	7.4	4.1

Table II—Results of Test Runs Using Isolation Sampling Procedure for Idle Operating Conditions

Run No.	Volume Sampled, Liters	Idle Time, Min.	Exhaust Discharge, scfm	H-C, ppm	CO_2, %	CO, %
1	0.98	10.1	5.6	800	10.4	2.8
2	1.20	8.7	6.7	740	9.4	3.2
3	1.16	8.7	6.4	790	9.8	2.6
Avg	1.11	9.2	6.2	780	9.9	2.9

Table III—Results of Test Runs Using Isolation Sampling Procedure for Acceleration Operating Conditions

Run No.	Volume Sampled, Liters	Accel. Time, Min.	Exhaust Discharge, scfm	H-C, ppm	CO_2, %	CO, %
1	15.5	13.5	61.7	320	10.6	3.9
2	14.3	13.2	60.2	300	10.2	3.9
3	14.0	12.4	62.6	360	9.4	4.9
4	13.8	12.3	62.3	360	10.0	5.1
5[a]	18.5	16.0	64.2	420	9.2	3.8
Avg	15.2	13.5	62.2	350	9.9	4.3

[a] Changed driver.

Table IV—Results of Test Runs Using Isolation Sampling Procedure for Cruise Operating Conditions

Run No.	Volume Sampled, Liters	Cruise Time, Min.	Exhaust Discharge, scfm	H-C, ppm	CO_2, %	CO, %
1	16.9	32.7	28.7	380	11.0	4.2
2	20.8	29.9	38.7	340	11.4	4.1
3	19.4	29.8	36.2	400	10.2	4.1
4	18.1	30.8	32.7	320	11.8	4.0
5[a]	15.8	28.5	30.8	320	8.4	2.8
Avg	18.2	30.3	33.4	350	10.6	3.8

[a] Changed driver.

Table V—Results of Test Runs Using Isolation Sampling Procedure for Deceleration Operating Conditions

Run No.	Volume Sampled, Liters	Decel. Time, Min.	Exhaust Discharge, scfm	H-C, ppm	CO_2, %	CO, %
1	1.38	16.4	7.7	2800	6.6	4.0
2	1.13	16.6	6.3	3000	8.0	4.0
3	1.20	15.8	6.7	3300	7.2	4.0
4	1.24	18.4	6.9	3300	7.6	4.4
Avg	1.24	16.8	6.9	3100	7.4	4.1

Table VI—Results of Test Runs Using Proportional Sampling System to Collect an Integrated Auto Exhaust Gas Sample

Run No.	Volume Sampled, Liters	Driving Time, Min.					Average Exhaust Vol., scfm	H-C, ppm	NO_x, ppm	CO_2, %	CO, %
		Idle	Accel.	Cruise	Decel.	Total					
1	31.1	12.4	14.1	25.2	15.6	67.5	27.6	570	860	10.0	3.8
2	31.1	16.7	15.2	23.2	17.8	72.7	25.4	570	910	10.6	3.8
3	31.7	16.0	14.4	23.6	16.0	70.0	25.6	600	—	10.8	3.9
4	33.7	13.1	14.1	23.5	16.8	67.5	27.4	580	750	10.4	3.8
5	28.3	11.5	15.5	27.4	16.6	71.0	22.2	560	—	11.6	3.5
Avg	31.2	13.9	14.7	24.6	16.6	69.8	25.6	580	840	10.7	3.8

Calculations

All calculations are based on the analytical data and the measured volume of the exhaust gas collected in the accumulator tank with respect to sampling time.

Exhaust Gas Discharge Rate

The method for calculating the average exhaust gas discharge rate for each sampling category is described in Table IX. The calculated proportioned volumes, with respect to a unit of vehicle operating time (one minute) is shown in Table VIII. The sum of the individual proportioned volumes represents the synthetic integrated exhaust gas discharge rate (scfm).

$$\frac{14{,}770}{27.8} = 530 \text{ ppm hydrocarbons}$$

The carbon dioxide and carbon monoxide synthetic integrated values are obtained in the same manner.

Gasoline Consumption

The gasoline consumed by the vehicle during a test run is determined by making a carbon balance based on the exhaust gas discharged (scfm × driving time in minutes) and the concentration of hydrocarbons (hexane equivalents), carbon dioxide, and carbon monoxide. The total quantity of "carbon" emitted is related to the gasoline consumed having a molecular weight of 100 (C_7H_{16}). The actual fuel consumption was metered by a Servis Fuelometer. The counter registered in gallons and tenths of gallons. Values of 1.6 and 1.7 gallons were registered during the test runs. An estimation of the gasoline consumed, to the nearest 0.05 gallon, is 1.65 gallons for the 28.7 mile test route.

Sampling Rate

The proportional sampler was calibrated to sample 18 ml per ft³ of exhaust gas discharge. This ratio can be checked by making a carbon balance at the termination of each test run as shown by the following calculations:

Volume Sampled..... 31.2 liters
Sampling Time..... 69.8 minutes
Carbon Atoms..... 14.3 mol %
Gasoline Consumed.... 1.61 gallons
Mol Wgt Gasoline.....100 C_7H_{16}

$$\frac{(31.2)(0.148)(12)}{(28.3)(379)(.84)} = 0.00615$$

lb gasoline equivalents accumulated during test run

$$\frac{(31.2)(1.61)(6.2)}{(28.3)(0.00615)} = 1790$$

scf total exhaust gas discharged during test run

$$\text{S.R.} = \frac{(31.2)(1000)}{1790} = 17.4$$

ml per scf exhaust gas discharged

Table VII—Comparison of the Synthetic and Actual Integrated Test Data Using the Proportional Sampling System

Basis of Comparison	Synthetic	Actual
Hydrocarbons, ppm	530	580
Carbon dioxide, %	10.0	10.7
Carbon monoxide, %	4.0	3.8
Gasoline consumption per test run, gallons	1.68	1.61
Air-fuel ratio	14.2	13.7
Hydrocarbon loss (hexane equivalents) as a weight percent of supplied fuel	2.60	2.73
Exhaust gas discharge volume		
(1) Average scfm	27.8	25.6
(2) CF per gallon of gasoline consumed	1150	1110

Table VIII

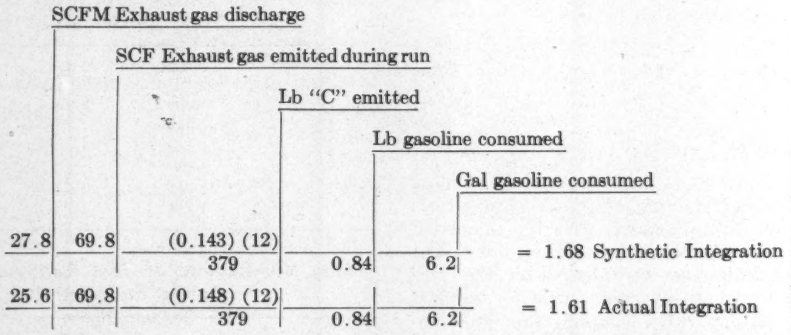
Operating Condition	Avg Volume, scfm	Ratio of Operating Time	Proportioned Volume Per Minute of Vehicle Operation, scf
Idle	6.2	0.199	1.24
Acceleration	62.2	0.211	13.1
Cruise	33.4	0.352	11.8
Deceleration	6.9	0.238	1.64
Synthetic integrated volume			27.8 scfm

Concentration of Exhaust Gas Components (Synthetic Integration)

Operating Condition	Proportioned Volume Per Minute of Vehicle Operation scf	H-C Concentration ppm	Proportioned Quantity
Idle	1.24	780	970
Acceleration	13.1	350	4,580
Cruise	11.8	350	4,130
Deceleration	1.64	3100	5,090
		Total Quantity	14,770

Table IX

	Constituent	Concentration, Mol %	Atoms C, Mol %	
Synthetic integration	H—C (C_8H_{14})	0.053	0.3	14.3
	CO_2	10.0	10.0	
	CO	4.0	4.0	
Actual integration	H—C (C_8H_{14})	0.058	0.3	14.8
	CO_2	10.7	10.7	
	CO	3.8	3.8	


SCFM Exhaust gas discharge
SCF Exhaust gas emitted during run
Lb "C" emitted
Lb gasoline consumed
Gal gasoline consumed
27.8 69.8 (0.143) (12) / 379 0.84 6.2 = 1.68 Synthetic Integration
25.6 69.8 (0.148) (12) / 379 0.84 6.2 = 1.61 Actual Integration

Conclusions

The proportional sampling system continuously meters and accumulates a constant percentage of the exhaust gas. The electronic and analytical evaluation studies indicate that the system is reliable within the desired overall accuracy of 90 percent and responds to the normal engine transient operating conditions throughout the test run.

The system eliminates the need of tedious manual integration of individual operating conditions. Overall evaluation of the exhaust gas emissions from a test run is obtained from one sample.

Limitations are not imposed on the number of analyses that can be performed or the techniques employed.

The accumulated sample can be used as a representative automotive gas source for many research experiments such as exhaust gas composition studies, reaction kinetics, plant fumigation and eye irritation studies.

REFERENCES

1. J. M. Chandler, W. A. Cannon, J. C. Neerman, and A. Rudolph, "Engine Variables and Their Effects on Exhaust Gas Composition," *J. Air Poll. Control Assoc.*, **5**, 2, p. 69 (August, 1955).
2. (a) G. H. Millar, and R. C. Stahman, "Engine Airflow Measurements as an Aid to Automotive Exhaust Analysis," *J. Air Poll. Control Assoc.* 6, p. 35 (May, 1956).
   (b) J. C. Neerman and G. H. Miller, "Determination of Hydrocarbon Emission Rate by Continuous Air Flow Measurement and Exhaust Analysis," SAE Seattle, Washington Meeting (August, 1957).
3. Extraction Thimble Filter, Whatman Single Thickness; 19x90 mm.
4. Kel-F Filter, Beckman Instruments, Inc.
5. Statham Laboratories, Inc., Los Angeles 64, Calif., Pressure Transducer Model PM5TC ± 0.15—350.
6. Statham Laboratories, Inc. Bulletin No. 1.
7. Arthur S. Iberall, "Attenuation of Oscillatory Pressures in Instrument Lines," *Journal of Research* of the National Bureau of Standards, Research Paper 2115, **45**, pp. 85–108 (July, 1950).
8. Video Instruments Co., Inc., Santa Monica, Calif., Model SR-200 Solid-State D-C Regulated Power Supply.
9. Video Instruments Co., Inc., Model 71-R D-C Amplifier.
10. Raymond Atchley, Inc., Los Angeles 64, Calif., Steady Current System.
11. Video Instruments Co., Inc., Model SR-1000 Solid-State D-C Regulated Power Supply.
12. Raymond Atchley, Inc., Model 620 313 Servovalve.
13. Abraham M. Fuchs, "Testing Servomechanisms," *Control Engineering*, p. 174 (September, 1956).
14. R. T. Van Derveer, J. D. Jenks, and R. L. Dennis, "An Integrator for Determining the Total Emission of Automotive Gas Components," S.A.E. Paper No. 169.
15. Gerald C. Gills, "A Fast Response Anemometer for Micrometeorological Investigations," Bulletin of the American Meteorological Society, **35**: 2, pp. 69–75 (February, 1954).
16. J. M. L. Janssen, L. Ensing, and J. B. Van Erp, "A Constant-Temperature-Operation-Hot-Wire Anemometer," Proceedings of the IRE, **47**: 4, pp. 555–67 (April, 1959).
17. Statham Laboratories, Inc., Pressure Transducer Model PL6a-15-350.
18. Minneapolis-Honeywell Regulator Company, Brown Instruments Division, Philadelphia, Pa., Type 153 ELECTRONIK Recorder.
19. APCD Automotive Laboratory Test No. AT-3, Unpublished.

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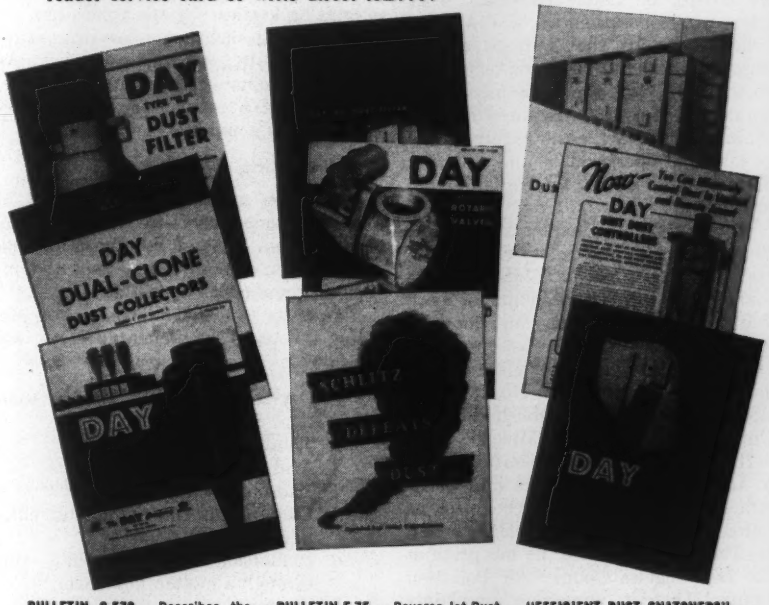

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EQUIPMENT ONLY OR A COMPLETE SYSTEM

Air Pollution Control Measures for HOT DIP GALVANIZING KETTLES*

ERIC E. LEMKE, Senior Engineer, **WILLIAM F. HAMMOND,** Senior Engineer
and **GEORGE THOMAS,** Air Pollution Engineer, Los Angeles County Air Pollution Control District

Introduction

This paper discusses the accomplishments and studies still in progress for the control of visible emissions from galvanizing operations in Los Angeles County. Before the findings of the various studies are discussed or conclusions drawn, the paper discusses: (1) the degree of controls required for galvanizing kettles; (2) the nature of the galvanizing operations; and (3) the characteristics of the air contaminants emitted.

Section 2422 of Chapter 2, Division 20 of the Health and Safety Code of the State of California prohibits the discharge of any air contaminants for more than three minutes in any one hour "of such opacity as to obscure an observer's view to a degree equal or greater than does smoke equivalent to No. 2 on the Ringelmann Chart, as published by the United States Bureau of Mines."

Hot-dip galvanizing operations, due to their discharge of odors and dense fumes (Fig. 1), are easily recognized as sources of both visual violations and local nuisances. Since the inception of the Los Angeles County Air Pollution Control District, numerous complaints have been received regarding odors and visible fumes annoying persons living or working near galvanizing shops.

The authors have attempted to discuss the basic process of galvanizing only to the degree required to form an understanding of the problem of controlling air contaminants. Various types of air pollution control equipment are discussed with respect to the problem that they must alleviate.

There are still some problems that must be solved before any control system can be widely accepted. The problem of hooding galvanizing operations is a major obstacle and a costly item. High canopy hoods are preferred by industry because they allow greater access to working space around the galvanizing kettles, yet the ventilation air volumes for such hoods are necessarily high to insure good fume collection. As the contaminated air volume increases, the size of a satisfactory fume collector increases and costs go higher.

Galvanizing Operation

Hot dip galvanizing is the art of coating clean, oxide-free iron or steel with a thin layer of zinc by immersion of the iron in molten zinc held at temperatures of 840°F to 860°F.

In order to achieve optimum results, the following fundamental steps are followed:

1. Degreasing in a hot, alkaline solution.
2. Thorough water rinse.
3. Acid pickling.
4. Thorough water rinse.
5. Prefluxing in zinc ammonium chloride solution.
6. Immersion in the molten zinc through a molten flux cover.
7. Finishing.

When considering the air pollution aspects of the galvanizing operation, one might skip over the first five steps because they do not normally produce excessive air contaminants. However, they do affect the generation of air contaminants when the article is immersed in the zinc, and under abnormal conditions, such as stripping previous zinc coatings in the pickling tanks, excessive acid mists can be generated.

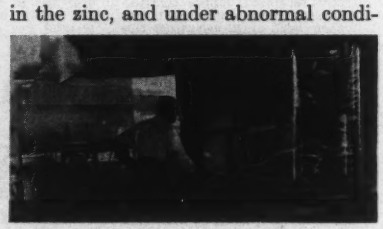

Fig. 1. Tank being removed from galvanizing kettle.

Cleaning. If an article is not thoroughly degreased, an oil mist will be discharged when the article is charged into the molten zinc. If the articles are not properly pickled and rinsed more flux must be used to achieve the desired coating thus creating more fumes. It is important, therefore, to thoroughly degrease, pickle and rinse the articles being galvanized, not only to obtain a good zinc coating, but also to reduce the generation of fumes and to facilitate the collection of the unavoidable fumes.

Cover fluxes. Assuming that the article was properly prepared for dipping in the molten zinc, it is still necessary to use a flux to remove the oxide film that forms as the article is being transported from the last rinse tank to the galvanizing kettle. To exclude air from the part after fluxing, the flux is floated on the zinc so the article entering the zinc is fluxed as it is being submerged.

It is believed that the flux creates the bulk of air contaminants from a galvanizing operation; therefore a description of fluxes, their composition and action, is in order. It is theorized that regardless of whether ammonium chloride or zinc ammonium chloride is used, the composition of the usable flux cover is molten zinc chloride in which ammonium chloride is absorbed and ammonia and hydrogen chloride gases are trapped. The active cleaning agent is the hydrogen chloride gas formed by the dissociation of ammonium chloride due to heat. Zinc chloride is present either because it was placed there with the ammonium chloride or due to the reaction of hydrogen chloride with the molten zinc. The zinc chloride is necessary to keep the active ingredient on the zinc surface.

To form a flux cover, ammonium chloride or, better, zinc ammonium chloride is placed on the molten zinc sur-

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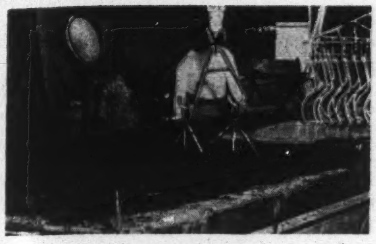

Fig. 2. Removing work through clean zinc surface; flux cover in foreground.

face. Usually a foaming agent such as glycerin is added to the flux before applying it to the kettle. If ammonium chloride is used, the heat from the zinc causes the salt to decompose forming hydrogen chloride and ammonia gases. Both of the gases tend to rise and escape from the kettle where they cool down and recombine forming a fume of ammonium chloride. The hydrogen chloride and zinc are very reactive, therefore, zinc chloride is formed which stays on the zinc as a liquid at the temperature of the zinc bath. Since some of the hydrogen chloride is used up in this reaction, the fumes escaping will have an excess of ammonia. As more ammonium chloride is added to the zinc surface the zinc chloride formed begins to absorb it. At the same time a foam filled with hydrogen chloride and ammonia gases is formed. The foaming agent increases the depth and fluidity of the foam. If foaming type zinc ammonium chloride is used as a starting material, the zinc chloride merely melts trapping the bulk of the gases formed and retards the decomposition of the NH_4Cl. The flux cover is made much more easily and with less fuming when foaming type zinc ammonium chloride is used in place of ammonium chloride.

The flux cover has a number of important functions in addition to the cleansing action already mentioned. It serves as a preheating and drying medium to reduce spattering or explosions in the molten zinc and distortion of thin metal sections. It keeps the zinc surface free of oxides which, if occluded in the coating, tend to dull it and retard drainage of zinc from the work. Heat losses from the kettle also are reduced.

Foaming Agents. If galvanizing is carried on using a thin layer of molten flux, a higher temperature is reached throughout the flux layer, inducing fuming and loss of flux ingredients. The flux becomes viscous and inactive in a short period of time, requiring frequent additions of fresh flux to keep it in prime condition. The thin molten flux cover can be fluffed up by additions of foaming agents such as glycerin, wheat bran, wood flour, sawdust, etc. The resulting deep foaming type of flux cover has the advantage of reducing the quantity of objectionable fumes. Some other advantages are longer flux life, greater ease of control in maintaining fluidity and fluxing activity, reduction of zinc spattering, and saving of flux, zinc and heat.

To achieve the required foaming action, a small but definite amount of foaming agent is added to the flux. Too little or too much accelerates the rate at which the flux becomes too viscous. To reduce the amount of fuming, the foaming agent should be mixed with the flux before it is placed on the surface of the zinc bath. Of the foaming agents mentioned, glycerin seems to be the most efficient. Observations of the fuming tendencies of various proprietary foaming type fluxes have shown that some fume more than others. The compositions of the proprietary foaming agents have not been revealed by the manufacturers.

Dusting Fluxes. After an article to be galvanized has been charged into the kettle through the flux cover, and while it is still completely immersed in the zinc bath, it is moved to a portion of the kettle where it can be removed through a clean zinc surface (Fig. 2). If the articles are small, such as bolts, nuts, nails, etc., they are usually dusted with powdered ammonium chloride immediately upon removal from the molten zinc. The dusting flux causes the zinc to flow and results in a smooth bright finish. The dusting must be done before the work has time to cool off, since the zinc coating must still be molten in order to flow and drain properly from the work. At the temperature of the molten zinc the flux will decompose and fumes will be generated.

Air Contaminants

Mechanics of Generation. Observations of many galvanizing kettles have revealed that air contaminants are discharged whenever the flux cover is disturbed, when fresh flux is added, and when dusting galvanizing objects with sal ammoniac.

Flux agitation occurs to some extent each time an object is immersed in the zinc through the flux cover. If the objects are smooth and dry the agitation is not great and the amount of fuming is low. When the agitation is severe a correspondingly larger amount of fumes is discharged. Mechanical actions which break some of the bubbles making up the flux cover release fume-forming gases.

When fresh flux is placed on a kettle it takes some time to form a foaming cover. During this time dense fumes escape. Also, when fresh flux is stirred into the existing flux cover, fumes are discharged due to both the agitation and the time necessary for the fresh flux to be absorbed by and become part of the foam. If the air contaminants were due only to the volatile constituent in the flux, the fumes would consist only of ammonium chloride. However, zinc, zinc chloride and oil, among other things, have been identified in the particulate matter discharged from galvanizing kettles.

Zinc and zinc chloride have very low vapor pressures at normal galvanizing temperatures, therefore, one would expect neither of them to vaporize to any great extent. It is believed that the discharge of these materials is the result of mechanical entrainment and occurs when wet articles are galvanized. Frequently an object is immersed too rapidly allowing some of the steam to vent into the molten zinc below the flux cover and the rapidly escaping steam atomizes some zinc and flux into the air.

Cases have been observed where the articles to be galvanized were not thoroughly cleaned. In one case, the cleaning and pickling solutions did not remove all of the lubricant from chain link fence material. The oil was vaporized and discharged as an oil mist with the fumes from the flux cover. The oil, in fact, made up about one half of the fumes discharged. In another case, sulfur was not removed from an object before charging to the kettle. The resulting fumes were yellow in color and much more opaque than would normally be expected.

To obtain brighter, smoother finishes, especially on small items, they are dusted with finely ground sal ammoniac immediately after being removed from the molten zinc. The items dusted are still at a temperature well above the decomposition temperature of sal ammoniac, therefore, nearly all of the flux is converted to fumes by the operation. Although only small amounts of dusting fluxes are used, they always create dense fumes.

Physical and Chemical Composition of the Air Contaminants. From the foregoing it can be reasoned that the appearance and composition of the fumes vary according to the operation being conducted. Observations and chemical analyses of fumes have shown this to be true, especially in the chemical composition. During a test made to measure the total discharge of air contaminants from a water scrubber serving a kettle, a sample was taken and analyzed. The fumes were generated during the galvanizing of strainers requiring dusting, castings and flat work. No hollow objects were treated. The analysis disclosed there was no zinc in the fumes. However, a sample was taken from a pilot scale baghouse serving the same kettle after a larger variety of articles were galvanized, including water heater tanks, racks made of pipe, other hollow objects, as well as flat work and finned coils. The analysis of this sample indicated the probable composition of the emissions to be as follows:

H_2O	2.5% by weight
$ZnCl_2$	3.6% by weight

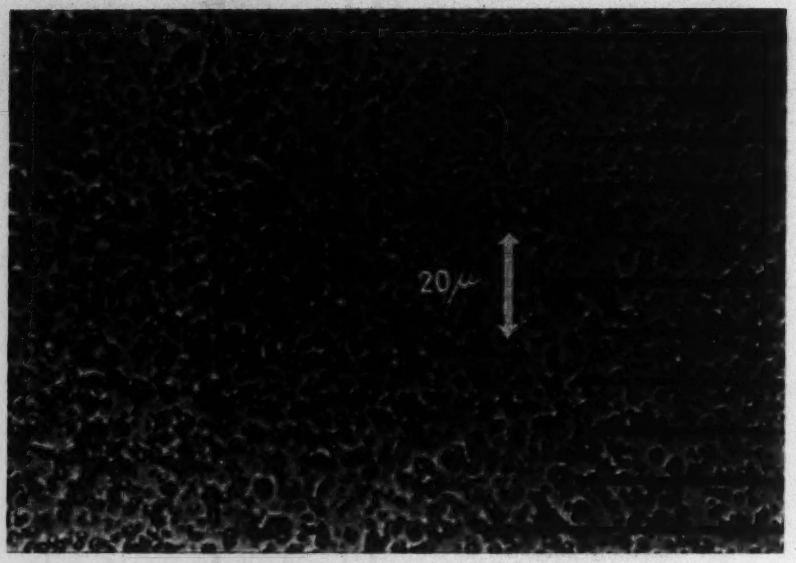

Fig. 3. Photomicrograph of fumes discharged from galvanizing kettle.

ZnO	15.8% by weight
Zn	4.9% by weight
NH_4Cl	68.0% by weight
NH_3	1.0% by weight
Oil	1.4% by weight
C	2.8% by weight

Although the zinc chloride content of the fumes was not high, zinc and zinc oxide accounted for a total of 20.7%. Neither oil nor zinc chloride were in sufficient concentration to make the fumes sticky enough to adversely affect the filter cloth.

The appearance of the fumes as discharged was similar to light gray smoke. The particles were so small that none settled. However, after being collected on a filter cloth, the fumes appeared to be spheres about $^1/_{16}$ of an inch in diameter. The spheres were agglomerates of microscopic-sized fume particles. Vigorous shaking of the material would not break up the agglomerates; however, when pressed between the thumb and finger the spheres reduced to a very fine powder. A mesh analysis indicated that 23 percent by weight of the particles were greater than 250 microns in diameter. However, microscopic analyses of the fumes as they are discharged from the kettle indicate that the average particle size was approximately two microns (Fig. 3). The particles were attracted to each other and then clung to the filter cloth making it difficult to remove them with a mechanical shaking device commonly used on baghouses.

Although fumes discharged from continuous chain link fence galvanizing have the same appearance as those from unit galvanizing, the chemical composition can be quite different. A sample collected by a pilot electrical precipitator serving the flux box of a chain link fence galvanizing kettle indicated the probable composition of the emissions to be as follows:

H_2O	1.2% by weight
NH_4Cl	23.5% by weight
NH_3	3.0% by weight
$ZnCl_2$	15.2% by weight
ZnO	6.5% by weight
Oil	41.4% by weight
Not identified	9.2% by weight

The high oil content was undoubtedly due to the vaporization of the oil from the fence material when it was charged into the zinc. The high zinc chloride content was probably due to loss of fresh flux. In this installation, flux was shoveled into a 10-inch wide flux box to which a slot hood was attached. The finer particles of the flux were undoubtedly drawn into the exhaust system.

The collected sample was immediately placed in a bottle and capped so that no moist air could reach it, therefore, the water content did not increase due to the delequescent nature of the zinc chloride.

Methods of Air Pollution Control

When it became apparent that some galvanizing kettles discharged fumes with an opacity in excess of that allowed by air pollution control law,* galvanizers began installing air pollution control equipment.

A baghouse and several water scrubbers were installed with no specific prior experimental nor developmental work. After it was found that none of these systems adequately controlled the air contaminants, experimental work was begun to determine a satisfactory type of control device. Baghouses were investigated independently by two firms, one with an experimental device (Fig. 4), the other with a pilot plant unit (Fig. 5). A third firm finding the presence of a large amount of oil in the kettle effluent investigated the use of an electrical precipitator. A discussion of these installations will be taken up later in this report.

Baghouses. The first control system used to control the emissions from a galvanizing kettle provided 14,600 cfm of ventilation air and 3600 ft^2 of filter area giving a filter ratio of 4 cfm/ft^2. Soon after the baghouse was placed in operation, the ventilation rate began to drop off. The original ventilation volume was insufficient to draw in all of the fumes generated and the decreasing volume soon allowed even more fumes to escape capture. However, the baghouse was effective to the extent that no visible emissions were discharged and the collected material was neither corrosive nor hygroscopic.

With the information now on hand, it seems apparent that the control system failed due to inadequate ventilation volume and filtering area. The cloth filter became plugged due to the high filtering velocity.

Another application of a cloth bag filter was investigated to determine the design parameters for a full scale baghouse to control emissions from a captive kettle to be used only to galvanize steel conduit. The mechanized operation of the kettle was such that a low canopy hood over the conduit entry point was permissible and the experimental system was similarly constructed. A small flux box six inches square by eight inches high, open on top and exhausted from one side was placed on an existing kettle. The installation consisted of a blower, a damper, an orifice flow meter (Fig. 4) and one 0 ft-6 in. diam x 10 ft-0 in. long cotton sateen filter bag. A manometer was used to determine the velocity of the air flow and the pressure across the filter cloth.

Zinc ammonium chloride was placed in the flux box and stirred to create fumes at approximately four times the rate expected from the actual galvanizing operation. The rate of flow of fume laden air and the pressure across the bag were recorded at regular intervals. Flow rates were varied for different runs, and for two of the runs the rate of addition of flux was doubled. Each run was conducted until bag pressure reached four inches of water or for four hours, whichever occurred first. After each run the material collected was shaken from the filter bag and weighed. The filter ratio, fume concentration, the time necessary to attain a four-inch pressure drop and the rate of increase in pressure were determined. The results

* Section 24242 of Chapter 2, Division 20 of the Health and Safety Code of the State of California.

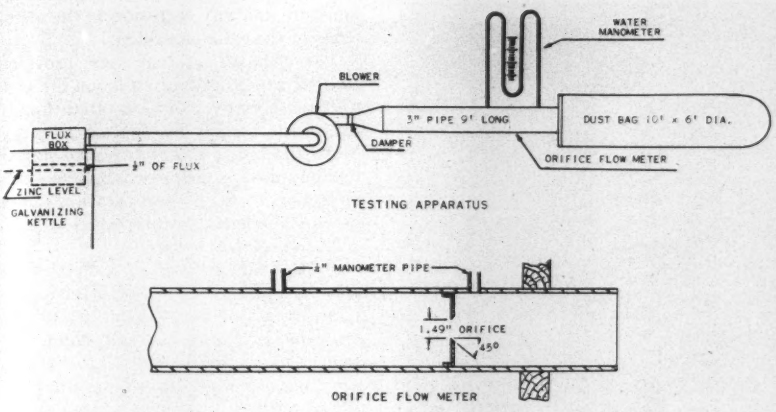

Fig. 4. Flux fume testing device.

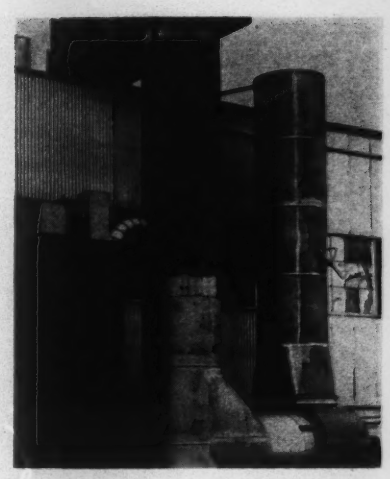

Fig. 5. Full scale exhaust system with pilot size baghouse at left.

of the experiments and calculations are summarized in Table I.

The firm reported that the fumes were nearly 100 percent ammonium chloride. However, this cannot be taken as the case in an actual galvanizing operation. In this case no galvanizing was done and the flux was merely placed on the zinc and stirred intermittently to maintain a dense fume discharge. With this method of producing fumes the fume concentration averaged 0.6 grain per cubic foot of exhausted air. In actual galvanizing operations the highest concentration recorded, even during the galvanizing of chain link fencing, was 0.17 grain per cubic foot. An average of 0.12 grain per cubic foot was obtained from three chain link fence galvanizing kettles tested. In galvanizing operations where high canopy hoods are employed, the concentration is lower. Concentrations as low as 0.002 grain per cubic foot have been measured.

When the filter ratio was increased, the time necessary to reach a given pressure across the bag decreased and it became more difficult to remove the fumes from the bag. By dividing the increase in pressure across the bag by the time lapse the rate of pressure increase was calculated for the various filter ratios used. A plot of the rate of pressure increase vs. filter ratio is shown in Fig. 6. The plot indicates that the rate of pressure increase is 3.4 times the increase in filter ratio.

The firm operating the experimental unit concluded that:

1. The fumes discharged were primarily ammonium chloride.
2. The cotton cloth bag filtered the fumes.
3. Filter resistance pressure increased rapidly at the higher filter ratios.
4. Lower filter ratios will result in minimum maintenance and maximum filter life.
5. There was no corrosion to metal parts and no cloth deterioration.
6. The fumes were not hygroscopic and did not cake in the bags.

As a result of this study, the firm designed a baghouse control system with sufficient filter area for a $^1/_2$ cfm/ft² filter ratio.

While this experimental cloth filter investigation was still in progress, another firm began a pilot plant baghouse study because their water scrubber was ineffective in controlling the kettle emissions. A small baghouse was installed so that a portion of the fume-laden air discharged from actual galvanizing operations could be conducted through it. With this arrangement the small baghouse was controlling a portion of the same emissions that a full scale unit would be required to control.

The pilot scale baghouse contained 480 square feet of cotton cloth filter area and was equipped with an automatically controlled cloth shaking device. A damper in the inlet duct limited the air flow of the exhaust fan to 1000 cfm. The filter ratio was varied by adjusting the number of bags in service.

For the first month and a half a filter ratio was maintained at approximately 2 cfm/ft². The baghouse was used continuously during the galvanizing kettle operations. The bags were shaken at various intervals and for varying lengths of time. The resistance

Table I—Experimental Baghouse Test Data

Run No.	Flow Rate, Cfm	Filter Ratio, Cfm/Ft²	Fume in Air Stream, Gr/Cf	Bag Pressure, Inches H_2O Initial	Bag Pressure, Inches H_2O Final	Time of Run, Hr	Time to Attain 4 Inch Pressure, Hr	Rate of Pressure Increase, In. H_2O/Hr
1	25.1	1.67	0.43	0.1	3.4	4	4.7[a]	0.825
2	22.2	1.48	0.72	0.2	3.5	4	4.6[a]	0.825
3	22.3	1.49	0.65	0	3.8	4	4.1[a]	0.95
4	23.2	1.55	0.48	0.1	2.7	4	5.9[a]	0.65
5	23.2	1.55	0.42	0	4.0	4	4.0	1.00
6	25.4	1.69	0.53	0.1	4.0	2.92	2.92	1.34
7	27.0	1.80	0.54	0.3	4.0	2.57	2.57	1.44
8	33.0	2.20	0.50	0	4.0	1.8	1.8	2.22
9	35.0	2.33	0.76	0.2	4.0	0.75	0.75	5.06
10	47.1	3.14	0.76	0.4	4.0	0.65	0.65	5.54

[a] Figures extrapolated to 4-in. pressure.

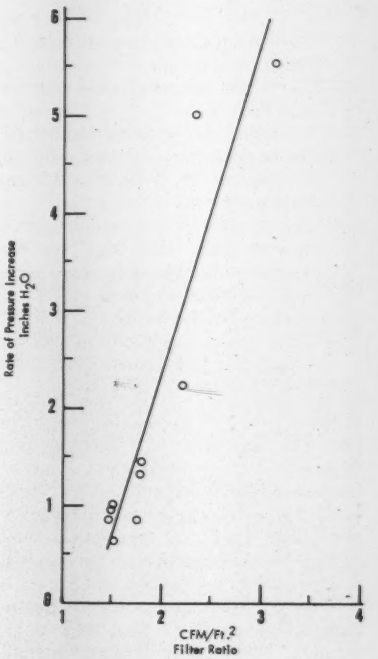

Fig. 6. Pilot showing resistance pressure increase vs filtering ratio.

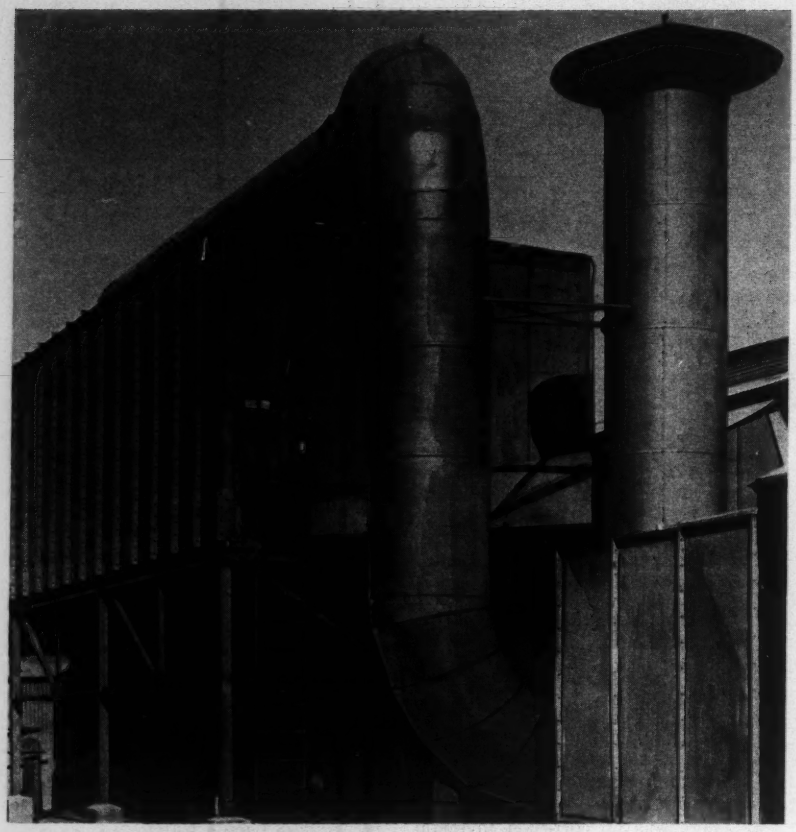

Fig. 7. Baghouse used to serve a galvanizing kettle.

pressure across the bags was measured immediately after shaking and the interior of the baghouse was inspected periodically. It was found that:

1 The cotton sateen bags filtered the fumes from the air.
2 The fumes collected were not hygroscopic.
3 For optimum operating conditions, the bags required shaking for 35 seconds at from four to eight hour intervals.
4 The fumes were not completely removed from the bags by the mechanical shaking device, therefore, the bags required individual shaking, by hand, once a month.
5 There was no evidence of bag deterioration nor corrosion to the metallic parts of the system.

The effects of increasing the filter ratio were then investigated. With a filter ratio of 3.1 cfm/ft² sufficient fume removal was still accomplished but vigorous shaking by hand was required in less than a week. Even then the pressure after shaking continued to increase. The filter ratio was then decreased to 2.7 cfm/ft² where it was found that by mechanically shaking the bags for 35 seconds every four hours, manual shaking would be required only once a week. The pressure drop after vigorous manual shaking did not appear to be increasing.

The pilot plant work and an associated study of the ventilation needed to capture all the fumes from the kettle, resulted in the modification of the existing exhaust system by increasing the ventilation to 36,000 cfm and installing a 13,200 ft² filtering area baghouse (Fig. 7).

For the first week the bags in the full scale unit were shaken mechanically at two hour intervals for about 1½ minutes. It was found that the pressure drop across the full scale baghouse, after shaking the bags, gradually increased. At the end of the week the bags were more vigorously cleaned by shaking each bag for three-seconds by hand. The pressure across the bags was reduced to that of the new bags by this cleaning method. Since then, this same operating procedure has been used.

After five months of operation the bags were still clean on the clean-air side indicating that no fumes had passed through the cloth. The resistance pressure after a week of operation with only mechanical shaking did not exceed four inches of water. After vigorous manual shaking the pressure drop was 3.5 inches of water, the same as it was when the bags were new. There was no apparent bag deterioration, no caking due to moisture, nor any corrosion to the metal parts of the exhaust system.

The exhaust system has provided sufficient ventilation to adequately pick up and convey the generated fumes. Emissions cannot be seen at the baghouse discharge and the control system has supplied sufficient ventilation and collection to keep the operation of the galvanizing kettle in compliance with air pollution control laws.

Pilot Plant Study of Low Voltage Electrical Precipitator.—A firm experimenting with a water scrubber to control the fumes from their chain link fence galvanizing kettle found that the scrubber did not reduce the visible emissions sufficiently to comply with the air pollution control laws and that the fumes contained excessive amounts of oil.

Because of the high oil content, the owners decided to try an electrical precipitator. To determine the feasibility of ionizing and collecting the fumes, a small two-stage precipitator designed for 150 fpm gas velocity was used. The precipitator was found capable of reducing the opacity of the effluent from 60 percent to 10 percent. However, after a short period of operation it was found that re-entrainment of the precipitated fumes occurred. The fumes had agglomerated and were released in a form resembling snow. It was then found that a water-to-fan type scrubber installed at the precipitator vent was effective in removing the agglomerated material.

A full scale precipitator with enough cross sectional area to be operated at 100 fpm gas velocity was installed between the kettle and the original scrubber (Fig. 8). This precipitator used two ionizer sections, one with standard three-inch spacing between wires, the second with only 1½-inch spacing between wires, and one collector plate section. The ionizers used 13,000 volts and the collector plates 9000 volts.

When the fume control system was in full operation, no visible emissions could be seen discharging from the vent. When both the scrubber and precipitator were turned off, emissions up to 80 percent opacity were discharged. A stack discharge analysis disclosed the combined precipitator-scrubber system had an overall collection efficiency of 95 percent. The removal efficiency across the precipitator alone was 91 percent and across the scrubber alone was 46 percent. However, the velocity of gases through the precipitator was only 58 fpm during the test. The exhaust system supplied 1750 scfm of ventilation, which was enough to capture the fumes generated in the flux box.

The concentration of total particulates in the gases handled was 0.154 grain per scf of which 41 percent by

Fig. 8 Experimental electric precipitator used in galvanizing control study. *(bottom right.)*

weight were oil. The oil provided a vehicle to hold the fumes on the precipitator collector plates.

Since this was a special case involving relatively concentrated fumes with high oil content, the performance of the precipitator could not be accurately predicted for fumes about $^1/_{100}$ as concentrated and with very little oil content. However, because of the good performance of the precipitator-scrubber control system it was decided to continue the investigation to determine how effective it would be in controlling dilute fumes. Investigation into the maximum desirable gas velocity through the precipitator will also be made.

A full scale exhaust system with a capacity of 36,000 cfm is being installed to capture the fumes generated from a job shop galvanizing kettle. The small precipitator-scrubber control system will be connected into the exhaust system so that only a portion of the fume-laden air is diverted to the precipitator. Air volumes will be varied in order to determine the collection efficiency at various flow rates. It is planned to determine if the fumes discharged from the kettle can be collected in a baghouse when material other than chain link fence is being galvanized. From these studies, an economic comparison between a baghouse and a precipitator can be made.

Scrubbers. Four firms have installed water-wash scrubbers similar to the one shown in Fig. 9 to control emissions from their kettles. Observations indicated that the amount of fumes collected by the scrubbers was less than anticipated. Stack discharge analyses were conducted to determine the collection efficiencies and the nature of the fumes discharged from two of them. The tests revealed greater amounts of particulate matter in the exhaust gas stream than in the entering gases. On checking the test results, it was evident that there was a greater increase in moisture content in the discharged gases than could be expected from evaporation, and upon investigation it was found that entrained water droplets were being discharged. The sampling equipment would, of course, pick up the contaminated wash-water carryover as well as the uncollected fumes. Water recirculated in a scrubber contains both dissolved and suspended matter; therefore, it is very possible to have more particulate matter discharged than is entering a scrubber if mist elimination is not effective.

All four scrubbers evaluated were similarly designed in that the gases were conducted around baffles, through water sprays and finally through mist eliminators. Water was recirculated through the scrubbers with only sufficient make-up to replace the amount lost due to evaporation and mist discharge. Table II lists the water flow rate, volume of gases scrubbed, water to air ratio, particulate matter entering and leaving the scrubbers and the collection efficiencies of the scrubbers tested. It seems apparent that water to air ratio is not the only criterion for good scrubbing. Other factors such as mixing and contact, fineness of water spray and mist elimination have a greater effect on scrubbing ability.

Microscopic analysis of the fumes entering the scrubber revealed the fumes have an average particle size of less than two microns (Fig. 3). Apparently there are so many small particles that a spray of water will not impinge upon enough of them to provide effluent removal. If more energy were expended to provide better contact between the fume particles and water such as in a venturi scrubber, increased efficiencies could be expected. One firm has decided that it would be more economical to filter the fumes with a baghouse than

Table II—Water Scrubber Performance Data

Scrubber	Water Rate, Gpm	Ventilation Rate, Cfm	Water to Air Ratio, Gpm/1000 Cfm	Particulates Entering Scrubber, Lb/Hr	Particulates Discharged, Lb/Hr	Collection Efficiency
A	560	2,870	195	0.54	0.57	Neg.[a]
B	140	1,750	80	0.13	0.07	46
C	920	22,000	42	2.7	3.4	Neg.[a]
D	490	16,940	29	ND	ND	ND

[a] Negative efficiencies may be due to entrainment of fumes concentrated in scrubbing water. ND—No data.

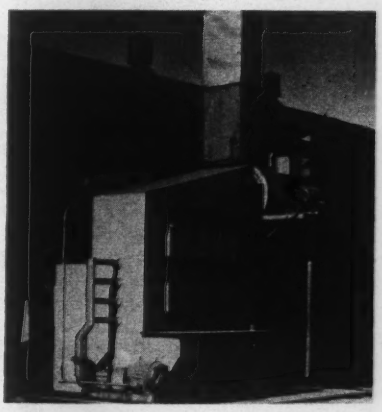

Fig. 9. Water wash scrubber serving continuous chain link galvanizing kettle.

Fig. 10. High canopy hood over galvanizing kettle.

to install a high efficiency scrubber.

The emissions from a water scrubber generally have an opacity much lower than the opacity of the fumes released from a galvanizing kettle. It is theorized that this reduction is due to dilution with air. In one case a scrubber with a collection efficiency of 0 percent discharged fumes of 20 percent opacity although the kettle it served emitted fumes of 100 percent opacity.

To confirm the dilution theory, the water sprays in the scrubber were turned off to see if any change in opacity would occur. The resistance pressure in the scrubber was reduced by turning off the water, thereby increasing the amount of ventilation air. In these circumstances no scrubbing was effected; nevertheless, the opacity decreased as predicted. This experiment was tried on other scrubbers and in each case the opacity either stayed the same or decreased. It appears that an exhaust system with no scrubber will discharge fumes of lesser opacity than the same system with a scrubber; however, since such a system does not reduce the amount of air contaminants, no air pollution control is effected.

Experiments were conducted by an independent testing firm with a laboratory scale venturi type scrubber. The system consisted of three aspirators in series—two operating with water and a third capable of operation with either steam or compressed air. Ammonium chloride fumes were created by heating beakers containing aqua ammonia and hydrochloric acid under a hood. The hood was ventilated by the aspirators. There were no measuring devices, however, they estimated the water and ventilation rates to be eight gpm and 30 cpm respectively. This arrangement did decrease the visible discharge but it could not be determined if the decrease was due to dilution with air or due to scrubbing. No further reports have been received concerning this project.

Capturing Air Contaminants. It is not within the scope of this paper to elaborate on the methods of hooding galvanizing kettles; however, it has been mentioned that capturing the fumes is a problem. In job shops the head room needed makes it imperative to use either high canopy or room type hoods (Figs. 10 and 11). The amount of ventilation volume required with a high canopy hood increases considerably with the height of the hood; therefore, the size of the collector must be increased to accommodate larger volumes.

Slot hoods are used only when the area of fume generation is small such as the flux box of a chain link fence galvanizing kettle (Fig. 12). The slot velocities needed to overcome the thermal draft for the entire surface of a large kettle will be high and large air volumes will cool the surface of a zinc bath. This cooling effect creates problems in applying a good zinc coating, and increases fuel consumption. When a slot hood can be used, the amount of ventilation required is smaller than with high canopy hoods and control devices are correspondingly smaller.

Low canopy hoods can be used when a kettle is used for only one or two products that do not require head room. Such hoods allow lower ventilation rates for adequate fume capture, therefore, smaller control devices can be used.

With lower ventilation rates the fume concentration in the exhaust air is higher. The low exhaust volume permits the use of small fume control devices. With some baghouses, capital costs are low enough so that additional filter area can be provided at relatively little additional cost. The lower filter ratios thus provided can be used to give much better fume control with an accompanying reduction in maintenance costs.

Summary and Conclusions

It appears, based on all investigations to date, that a properly designed baghouse will provide a suitable control device for galvanizing operations. The fumes from galvanizing operations, where the material to be galvanized has been properly degreased, do not damage cotton bags. The useful life of cotton bags is satisfactory provided ordinary good maintenance is observed.

Fig. 11. Opening to room type hood over galvanizing kettle.

Fig. 12. Hooding over chain link galvanizing flux box.

Observations and tests of precipitator installations indicate that this type of collector will be satisfactory although more data must be compiled to determine whether or not the first results can be extrapolated to provide design data for larger installations.

To date no scrubber installations have proved really effective to diminish the fumes discharged to the atmosphere, and wet collection systems invite corrosion problems.

Investigations are being continued to develop the most practical means of control for galvanizing operations.

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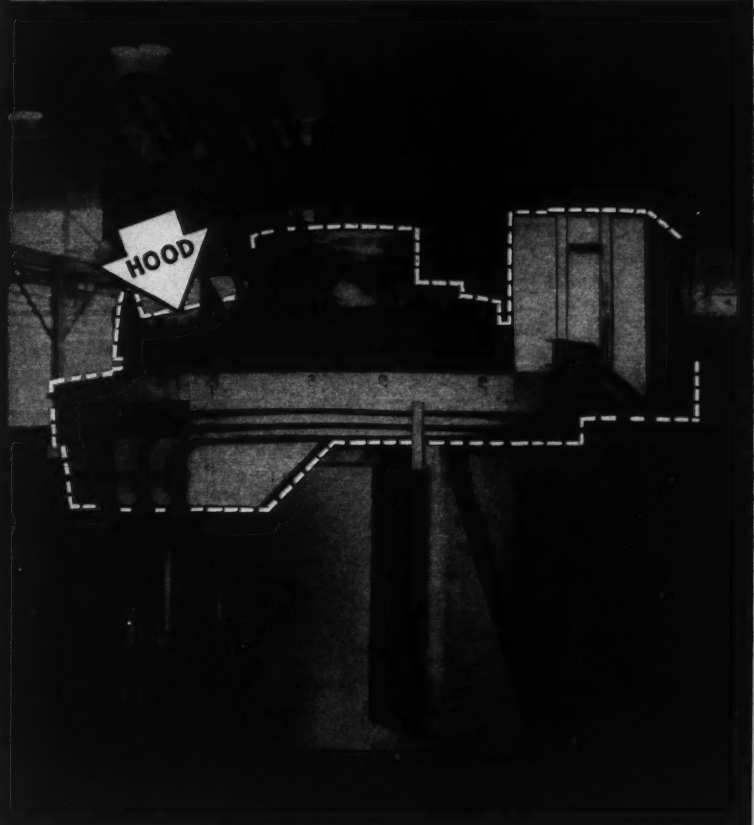
The faculty concerned directly with this program includes Professors T. F. Hatch, Professor of Industrial Health Engineering; W. C. L. Hemeon, of Hemeon Associates, Air Pollution Research Engineers; Lee Schreibeis, Acting Director of the Allegheny County Division of Air Pollution; and M. A. Shapiro, Associate Professor of Sanitary Engineering. In addition, the teaching program is assisted by visiting lecturers who are authorities in the several aspects of air pollution.

For further information and application blanks, write to Professor M. A. Shapiro, Graduate School of Public Health, University of Pittsburgh, Pittsburgh 13, Pa.

CONTROL ELECTRIC FURNACE FUMES



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Pangborn CONTROLS DUST

Control of Organic Emissions from SURFACE COATING OPERATIONS*

CARL V. KANTER, JACK H. ELLIOTT, EMMET F. SPENCER, JR., NORMAN KAYNE, and MARC F. LEDUC, Los Angeles County Air Pollution Control District

Abstract

At the present time no attempt is made to capture and recover organic solvents emitted to the atmosphere in industrial protective coating operations. This quantity is estimated to be in excess of 100 tons per day in Los Angeles County.

Possible methods for controlling these emissions including condensation, absorption, adsorption, chemical reactions, and vapor incineration are critically evaluated. The evaluation indicates that adsorption with activated carbon is the most feasible method.

A pilot plant has been constructed with sufficient flexibility to determine the economic and technical aspects of adsorption, desorption, and solvent recovery. The design of the pilot plant, consisting of a water-wash spray booth, an activated carbon unit, a variable speed blower, a boiler, a superheater, and a condenser, and its operation are discussed.

Preliminary investigations were made with three pure solvents—methyl ethyl ketone, toluene, and aliphatic mineral spirits. Complex solvent mixtures, typical of those found in various surface coating formulations, have been tested.

Paints, lacquers, and enamels will also be sprayed so that optimum design parameters and standards can be established. Variables under investigation include the optimum carbon bed thickness, pressure drop through the bed, the type of pre-cleaners required to protect the carbon, optimum number of adsorbing vessels, the desorption requirements, overall solvent recovery efficiency, capital costs, and operating expenses.

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26, 1959, Los Angeles, Calif.

† This program has been partially financed through Demonstration Grants from the United States Public Health Service.

Research conducted by various organizations on the probable cause of the smog in the Los Angeles Basin indicates that a major contributing factor is the action of sunlight on organic vapors in the presence of nitrogen oxides. As control methods became available, rules have been adopted to control petroleum vapors discharged to the atmosphere. Others sources of organic vapors remain uncontrolled at the present time.

A survey recently conducted by the Los Angeles County Air Pollution Control District determined that approximately 800,000 pounds or organic solvent vapors are discharged daily to the atmosphere.[1] More recent District data indicate 25 percent of this loss results from industrial surface coating operations. Unfortunately these 100 tons per day are not discharged from a limited number of large units. Rather, it is released from at least 5000 spray booths, dip tanks, and flowcoaters with solvent losses varying from less than one pound per day to as high as 3130 pounds per day.[2] Additional solvent losses result from the baking and forced drying of surface coatings.

At the present time no satisfactory control device is available for spray booths, dip tanks or flowcoaters. The problem is one of removing vaporized solvents discharged in relatively low concentrations. A survey conducted by the Engineering Division of the District of the average discharge of solvents from paint spraying operations indicates the concentration of organic vapors released is in the neighborhood of 100–200 ppm (one pound of solvent vapor per 40,000 cubic feet of air). The vapor concentrations in the discharged air are limited by the safety requirements that must be met. The per cent of flammable organic material must not exceed 25 percent of the lower explosive limit of the particular material used in order to meet fire hazard safety rules. In addition, sufficient ventilation must be provided to protect the health of the operator.

The District has undertaken to develop equitable control methods which will prevent or materially reduce the discharge of organic vapor from surface coating operations.† Both the spraying and baking phases of the problem are being investigated.

The conclusion reached from a study of possible control methods indicates that adsorption is the most feasible. A pilot plant using activated carbon as the adsorbent has been constructed, and experimental work to determine the economic and technical aspects of adsorption has been partially completed.

Evaluation of Control Methods

As the initial phase of the program, the literature was searched to critically evaluate the possible means of controlling the solvent emissions from protective coating spraying operations.[3]

In evaluating any method of solvent recovery it must first be considered if its characteristics will permit safe operation. Other important criteria by which a recovery process must be evaluated are: recovery efficiency, recovery expense, flexibility to meet varied operating conditions, and relation between initial cost and saving.

All of the solvent recovery processes known so far make use of one or more of the following operations: condensation by cooling or compression, adsorption, and absorption. In addition to these recovery methods, vaporized solvents can be eliminated by incineration producing carbon dioxide and water.

Condensation by Cooling

Solvent vapors can be recovered by condensation when the vapor-gas mix-

ture is cooled below the dew point. This is accomplished by bringing it directly or indirectly into contact with a cooling medium such as water or a refrigerated solution. When the cooling medium is water, the temperature of the mixture cannot ordinarily be reduced below 70°F. If the dew point is 70°F or higher, the minimum concentration of practically all commercial solvents is either in or above the explosive range. Water vapor present may also be condensed and if water soluble solvents are recovered by such a condensation method, the condensate must be distilled. If the coolant is a refrigerated brine, the temperature of the mixture should be maintained above 32°F to prevent the formation of ice from the moisture present in the air. It is evident that the recovery of solvents by condensation within the above temperature limits is not feasible in the case of surface coating operations.

The vapor concentration of the effluent from paint spray booths is well below the lower explosive limit. As mentioned previously, the vapor concentration in the typical Los Angeles County spray booth discharge is about one pound per 40,000 cubic feet of air. Since the dew point is a function of the partial pressure of the vapor, the temperature required for condensation at this low vapor concentration approaches the freezing point of the solvent. With most paint solvents this requires cooling the vapor-gas mixture below minus 100°F. For example, the freezing point of toluene is minus 135°F and methyl ethyl ketone freezes at minus 123°F.

The resulting refrigeration requirements are costly. For example, to obtain 90 percent recovery of a 250-pound per day toluene loss at a vapor concentration of one pound per 40,000 cubic feet of saturated air at 70°F and atmospheric pressure requires about 520 tons of refrigeration, assuming 100 percent thermodynamic efficiency. A much larger refrigeration system would be required in actual practice.

According to Scheflan and Jacobs,[4] recovery by condensation is probably applicable only to mixtures containing at least 200 grams of solvent per cubic meter of air (equivalent to one pound of solvent per 80 cubic feet of air).

Condensation by Compression

Since condensation can also be achieved by increasing the total pressure of the system, calculations were made to determine the final pressure and horsepower requirements for removing 90 percent of the solvent vapor from air streams at typical Los Angeles County spray booth effluent concentrations. For example, at one pound of toluene per 40,000 cubic feet of air at 70°F and 760 mm total pressure, the final required pressure is calculated to be 815 atmospheres or 12,000 psi. The required high volume, high pressure compressor is not standard equipment and would require a special design. High pressure compressors are generally built only for laboratory work for low volumes. Assuming a six-stage compressor, ideal gas behavior, perfect intercooling, and reversible adiabatic compression, it is calculated that 53.5 theoretical horsepower is required per 1000 cfm. Assuming 75 percent overall efficiency, the actual power required is 71.4 horsepower per 1000 cfm.

Condensation can also result if the gas stream is compressed, cooled, and adiabatically expanded. However, no evaluation of this method will be attempted because of the high pressures and low temperatures previously mentioned.

All of the information available seems to indicate that condensation of solvent vapors at low concentrations has many disadvantages. To obtain sufficient recovery a large capital investment is required with high operating expense. Condensation does not appear to be sufficiently flexible to contend with the numerous varied operating conditions which exist in surface coating operations.

Absorption

To recover solvent vapor by absorption in liquids, it is necessary to pass the vapor-laden air in intimate contact with the absorbent under conditions which will permit the liquid, at suitable temperature, to extract the vapor from the air. Contact may be effected by the use of spray chambers or scrubbing towers.

When water soluble solvents are recovered, water is the normal absorbent; if the solvent is not soluble in water, a mineral oil is generally used. Both of these absorbents hold solvent vapors in accordance with Henry's Law which states that a volatile substance dissolved in a liquid exerts a vapor pressure proportional to the amount of the substance present.

The driving force which determines the amount of material that can be absorbed thus depends on the concentration of vapor in the gas and its temperature. When the vapor pressure of the organic vapor in the liquid equals that in the gas phase, no further reduction of the concentration is possible. This means, of course, that the amount of solvent vapor which the absorbent liquid will hold and the practical recovery efficiency of such an absorbent are dependent upon the concentration of vapor in the air passed to it. It also means that it is impractical to remove all of the vapor from the air by such absorbents, since with a low concentration of vapor in the gas phase, either a long contact time or a large volume of absorbing liquid is required to maintain the vapor pressure of the solvent in the liquid below that in the gas phase.

According to Ray[5] the method of recovering solvent vapors from air by absorbing in mineral oil having a low vapor pressure is of limited applicability and use. He states, "It may be said in general that when the concentration of the vapor to be recovered is low enough to be safe, recovery by oil absorption is relatively inefficient and expensive."

Control of solvent emissions by means of absorption does not appear to be promising because the low vapor concentration results in a high capital cost for the scrubbing tower, the stripping tower, and the numerous heat exchangers required. In addition, economic operation of an absorbing system is predicated upon continuous operation. Such a system has no flexibility if the spraying operation is intermittent.

Chemical Reaction

Another possible method of controlling the emissions of organic solvent vapors is to modify chemically the solvent vapor to produce a more easily collected material or non-polluting material.

The more commonly used paint solvents can be broadly classified as aliphatic hydrocarbons, aromatic hydrocarbons, alcohols, ketones, esters and ethers. Many of the possible chemical reactions for these types of compounds were investigated. With the exception of oxidation by incineration, there appears to be no one chemical reaction suitable for the various types of solvents used. Recovery of the organic gases by chemical reaction does not appear adaptable to the problem.

Vapor Incineration

In addition to solvent recovery methods previously discussed, vaporized solvents can be eliminated by incineration producing carbon dioxide and water. This method is most commonly used in Los Angeles County to control the emissions from surface coating bake ovens. The incineration equipment must be designed to heat the contaminated gases to high temperatures for both catalytic and noncatalytic combustion. Higher temperatures are required for the latter.

A survey of a number of typical paint spray booths recently evaluated by the Engineering Division of the District indicates an average solvent concentration of one pound per 40,000 cubic feet of exhaust air. The low concentration is required to comply

with fire insurance regulations (less than 25 percent LEL) and with industrial health requirements which define the maximum average concentrations to which workers may be exposed for an eight-hour day without injury to health. In addition, with low winter heating costs, local firms are prone to provide excess exhaust volumes.

Inspection of the maximum concentrations allowed for a number of commonly used solvents indicates that 21,000 cubic feet per pound is probably the minimum exhaust volume which will allow sufficient flexibility to spray the various types of industrial surface coatings, with their myriad mixtures of solvents and diluents.

Figure 1 has been prepared showing the minimum cost in Los Angeles County of natural gas required to preheat spray booth effluent to a temperature sufficiently high to insure complete combustion. The gas cost was obtained from Southern California Gas Company Schedule G40 and an average of summer and winter rates was used. The gas required was calculated for 40,000 cubic feet of air per pound of solvent and for 21,000 cubic feet of air per pound of solvent. Heat losses were neglected so the cost shown is a minimum figure. The booth was assumed to operate eight hours per day, 22 days per month.

Toluene, commonly used with enamels and lacquers, has an auto-ignition temperature of 1026°F. If a minimum preheat temperature of 1050°F is assumed for direct flame combustion, the minimum fuel cost is $0.45 per pound of solvent at average Los Angeles County concentrations. This minimum cost can be reduced to $0.24 per pound of solvent if the solvent concentration is increased to one pound per 21,000 cubic feet of air. Assuming a catalytic unit can reduce the required preheat temperature to 600°F, these fuel costs are reduced respectively to $0.22 and $0.12 per pound of solvent.

Eleven direct flame afterburners recently installed on ovens in Los Angeles County had an average installed cost of $3.40 per scfm with a range of $1.86 per scfm to $5.80 per scfm. Seven catalytic afterburners installed during the same period showed an average installed cost of $5.86 per scfm with a range of $4.50 per scfm to $7.50 per scfm. The wide cost differential is probably due to differences in the instrumentation and automatic devices installed with the various units.

Fuel costs are less for catalytic type units since the contaminated gases do not require heating to as high a temperature. Catalytic incineration is more expensive to install because a precious metal catalyst must be provided. Its eventual reactivation or replacement must also be considered. Maintenance of direct flame vapor incinerators is approximately the same as for any furnace or other combustion device.

Solvent vapors can be eliminated satisfactorily by either combustion method, depending upon the requirements and the individual conditions. However, unless the process or plant can efficiently utilize the heat generated, the capital cost and operating expense are sufficiently high that vapor incineration is not attractive as a means of controlling solvent vapor emissions.

Adsorption

Adsorption should be sharply differentiated from absorption in that adsorption is commonly without chemical reaction between the adsorbate and adsorbent, while adsorption refers to more or less permanent chemical reaction or phase change as a function of the operation. Adsorption may be defined as that operation which deals primarily with the utilization of surface forces and the concentration of materials on the surface of solid bodies referred to as adsorbents.[6] To this end adsorption is used to (1) separate gases from gases as in deodorization; (2) separate vapors from gases as in solvent recovery or moisture elimination; (3) separate solutes from solvents as in decolorization; and (4) separate gases from gases selectively to effect fractionation. Many solids, porous in nature, each with definite characteristics as to affinity and selectivity for various gases and vapors, have been developed industrially to be used toward the ends mentioned above.

The adsorbents can be chosen from a wide variety of activated carbons, gels, chars, clays, alumina, oxides, and silicates. Of these, activated carbon, silica gel, activated alumina, and activated bauxite have been developed for gas adsorption. The latter three are used primarily for moisture elimination, as they have their greatest affinity and selectivity for water. Only activated carbon adsorbs organic material preferentially over moisture.

Activated alumina and bauxite show little or no retentivity for organic vapors. Silica gel can retain organic vapors and is used to recover gasoline from natural gas and for selective adsorption of aromatics from saturated hydrocarbons. However, the gas must be dry or the moisture will displace any organics adsorbed on the gel. Carbon shows a selectivity for adsorbing organic vapors over water vapor.

Activated carbon appears to be the adsorbent most suitable for recovering organic solvent vapors. The carbon adsorbs substantially all the vapor from the air regardless of variation in concentration, temperature, and humidity conditions. Because the adsorbed sol-

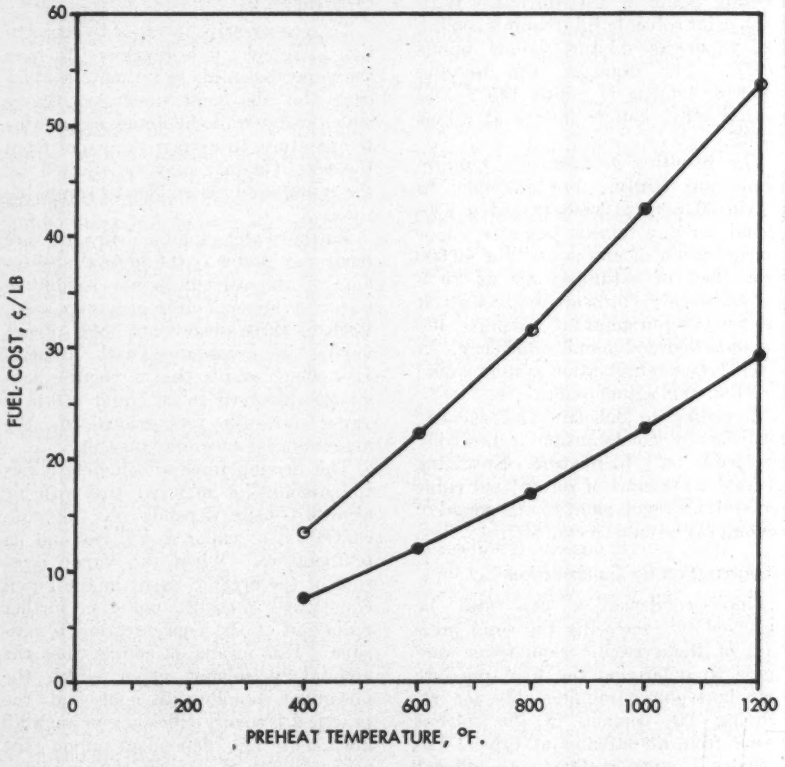


Fig. 1. Preheat fuel cost for vapor incineration.

vent has practically no vapor pressure at normal temperatures, the carbon system is particularly adapted for the efficient recovery of solvents present in air in low concentrations. This means the system can always be designed for operation without hazard because the vapor concentration is always below the flammable range. A number of activated carbons are now available possessing a high specific adsorptive power for organic vapors and therefore recover such vapors efficiently when water is present in the air or in the carbon. Since activated carbon adsorbs all of the usual low boiling solvent vapors, it can be used to recover practically any single solvent or any combination of low boiling solvents vaporized in surface coating operations.

When the carbon approaches saturation, it is economically desirable to recover both the solvent and carbon for reuse. This regeneration is usually accomplished by stripping with superheated live steam. The temperature necessary depends upon the solvent to be recovered. The lower the boiling point, the lower the temperature needed. The steam and revaporized solvent are then condensed and separated, so that the recovered solvent may be used again. The carbon is cooled and ready for reuse.

In general, fixed bed adsorbers have not been installed for solvent recovery purposes when a solvent-laden stream contains less than 0.2 lb of solvent per 1000 scf of gas. However, high efficiency recovery of undesirable constituents from a gas can be obtained by adsorption with much lower initial concentrations.[7] Adsorption is virtually 100 percent efficient and independent of concentration until saturation is reached.

The cost of operating an activated carbon system is relatively low. Mantell[8] states that the recovery expense, although varying, may be less than 0.2 cent per pound and very seldom exceeds one cent per pound of recovered solvent.

The overall recovery efficiency is usually between 90 and 95 percent depending almost entirely on the effectiveness of the vapor collection system. With well designed hoods, overall efficiency of 90 percent can be expected.[9]

Adsorption of the solvent vapors appears to be technically and possibly economically feasible if activated carbon is used as the adsorbent. Some of the outstanding advantages of activated carbon which are causing such adsorption systems to replace other methods are (1) recovery of solvent vapor in concentrations below the flammable range; (2) recovery of all types of volatile solvents; (3) low recovery expense; (4) recovery of solvents efficiently in the presence of water vapor; (5) recovery of solvent vapors with high overall efficiency; (6) adaptability to completely automatic operations; and (7) moderate recovery plant investment.[10]

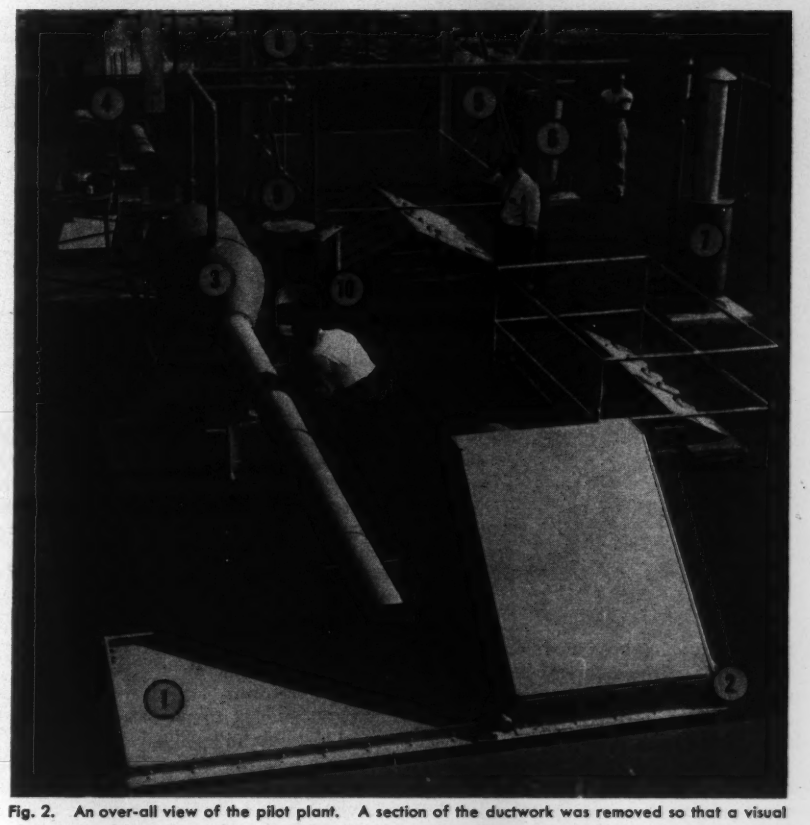


Fig. 2. An over-all view of the pilot plant. A section of the ductwork was removed so that a visual observation of the carbon, after adsorption, could be made. The engineer is checking the inlet sampling station to the carbon unit. Note that the flanges at both ends of the carbon unit are set in the closed position ready for desorption. The equipment is as follows: (1) spray booth; (2) dry filter tray; (3) activated carbon unit; (4) blower, with 5 hp varidrive; (5) water softener; (6) 5 hp boiler; (7) superheater; (8) condenser; (9) decanter; (10) scale for weighing condensate.

Conclusions from the Evaluation

Evaluation of the various methods of controlling paint spraying operations indicates that adsorption of the solvent vapors by activated carbon offers the greatest promise for controlling these emissions, from both a technical and economic point of view. It is sufficiently flexible to remove and recover the many different types of solvents used by industry. Whether the spraying is continuous, as in the automotive assembly plants, or intermittent, as in the many job shops, garages, etc., the efficiency of adsorption is not affected. Furthermore, the carbon adsorbs virtually all of the usual solvent vapors regardless of variation in concentration.

Because the apparent advantages of adsorption with activated carbon dictated further investigation, a small pilot plant has been designed and constructed.

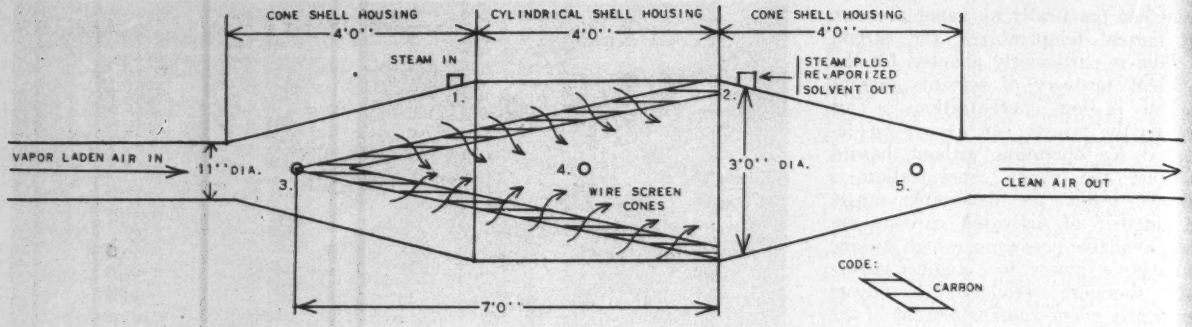
Paint Spraying Test Equipment

The experimental equipment consists of a water-wash paint spray booth, an air compressor and spray gun, an activated carbon adsorption vessel, a low pressure steam generator, a superheater, a condenser, and a variable speed exhaust fan. Figure 2 shows the overall layout of the pilot plant.

Spraying Equipment

The paint spray booth is a standard water-wash booth with a face opening of 3′W x 4′-6″ H. A 2-hp water recirculation pump, with a rated capacity of 105 gpm at 40 feet head, serves the water-wash section. The ex-

Fig. 3. Placing dry filter tray in position in spray booth.



NOTES: 1. Wire screen cones hold carbon and are placed 2 1/4 inches apart. These cones have stiffeners and supports. Wire is galvanized hardware cloth. The screen is made of 0.017 inch diameter wire with 0.108 inch opening.
2. All shells are constructed of 12 gauge mild steel and are insulated.
3. All connections (i.e. cylindrical shell to cone shell, cone shell to duct, etc.) are flange bolted.
4. Holes for tests, gauges, bleeders, etc., are shown and numbered.

Fig. 4. Experimental fixed bed adsorber.

haust plenum has been modified with the addition of a removable tray holding dry paint filters of the type normally used in dry filter spray booths (Fig. 3). Two filters are used, one 20 in. x 25 in., and one 16 in. x 25 in. Thus the booth can be used as either a dry or a wet booth or a combination of the two so as to determine the best method for removing the particulate matter in the overspray. The elimination of particulate matter is essential in adsorption systems so that the pores of the adsorbent will not be come plugged.

The spraying equipment includes a $^1/_3$-hp air compressor, a $2^1/_2$-gallon pressure paint tank, a rotameter to measure the solvent or paint flow rate, and a commercial paint spray gun.

Adsorption Equipment

Several commercially available adsorption units were considered but were either too expensive or insufficiently flexible for the proposed experimental work. A number of adsorption vessels were considered and three of these have been selected for additional study.

The first activated carbon unit installed consists of two concentric wire screen cones, 3 ft diameter x 7 ft long. The cone is in an insulated steel housing. The carbon used is in pellet form of four to six mesh with a net weight of 170 lb for the unit. The net unobstructed area is 20.2 sq ft. The wire screen used is eight by eight mesh. As can be seen in Figs. 4 and 5, the carbon is placed between the two cones. Both the air and stripping steam enter from the outside of the cone and travel through the $2^1/_4$ in. deep bed of carbon to the inside of the cone. The vertex of the cone faces the spray booth.

The time required to saturate the carbon has varied from three to 10 hours, depending on the solvent and its concentration.

It is planned to investigate another fixed bed unit and one moving bed unit. These are shown schematically in Figs. 6 and 7, respectively, as no final designs have been made for these units.

To provide the necessary ventilation for the spray booth, a blower and a variable speed 5-hp motor are used. The blower can provide indraft velocities of 100 to 150 fpm (1350–2000 cfm) to the face of the booth. The conveying velocities, in the 11-in. diameter ducts, are 2000 to 3000 fpm.

Desorption Equipment

Desorption of the carbon after it has become saturated is accomplished in the same housing as is used for adsorption. Therefore, the housing has been insulated with a 2-in. layer of 85 percent magnesia. Combination open-blind flanges are used to place the carbon unit on either the adsorption or desorption cycle. During desorption the flanges are reversed to the closed position in order to isolate the unit from the spray booth and blower. Desorption is accomplished by introducing live, superheated, low pressure steam. The stripping equipment, shown in Figs. 2 and 8, consists of a water softener, a five-hp steam generator, and a superheater with a heating capacity of 150,000 Btu/hour.

The discharge from the carbon unit, consisting of revaporized solvent and steam, vents to a small helical condenser with a heat transfer surface of 10 sq ft. The cooling medium is city water which is sewered. The condensed vapors flow to a decanting vessel. The condensate rate is determined by weight difference. If the solvent is water immiscible, it is recovered by simple decantation. If the solvent is water miscible, further processing is required.

Instrumentation

The instrumentation used is all standard equipment. A mercury manometer connected to the recirculating water pipe of the spray booth, measures the water scrubbing rate, which can be varied. A calibrated rotameter on the outlet side of the paint pot measures the solvent or paint rate to the spray gun. This rate can be varied by means of a needle valve connected to the outlet of the paint pressure pot. The air flow rate through the system during adsorption is measured by means of a calibrated orifice plate and water manometer. The flow rate can be varied by changing the speed of the fan. This, in conjunction with varying solvent rates to the spray

Fig. 5. Filling screen cones with activated carbon.

gun, allows the entire concentration range to be studied, and also permits determination of the pressure drop through the carbon bed at different air velocities. An Ellison gauge is used to measure the pressure drop.

A thermometer is placed at the inlet and outlet to the unit to measure any temperature difference through the carbon bed that might occur. Inlet and outlet sampling ports have been provided in the duct work to determine adsorption efficiencies and to determine when the carbon has become saturated The sampling ports have been placed 10 duct diameters downstream from any bend or constriction to assure uniform air flow so representative samples may be taken.

Desorption instrumentation consists of pressure gauges and thermometers at the boiler, superheater, and carbon unit to measure the temperature and pressure of the steam going to the carbon unit and the temperature of the vapors leaving the unit and going to the condenser. The condenser cooling water inlet and outlet temperatures are also measured. The decanting drum is placed on a scale and periodic weight readings give the condensate rate to the decanter.

Analytical Methods

Since the concentration of organic vapors emitted from paint spraying operations may vary from zero to several hundred parts per million, it was necessary to develop a suitable procedure giving reproducible results within these concentrations.

A satisfactory method[11] has been developed in which the organic vapors are catalytically oxidized to CO_2 which is measured by a nondispersive infrared analyzer.

Vapor samples are collected with evacuated 250-ml gas sampling bulbs. Glass stopcocks and ground ball joints are mandatory for the sampling bulbs as rubber removes certain organic vapors which may be present. The sample is then displaced by mercury at a rate of 25-ml per minute and passes through a bed of copper oxide maintained at 700 to 750°C. The resultant CO_2 is measured by the infrared analyzer and indicated on a recorder.

The background CO_2 is determined by diverting the sample stream directly to the infrared analyzer, by-passing the catalyst. The difference in the CO_2 concentration of the oxidized and unoxidized sample determines the vapor concentration.

This method gives reproducible results to one-half a scale division on the recorder which corresponds to 11 ppm CO_2. Satisfactory results have been obtained measuring methyl ethyl ketone, toluene, mineral spirits, and combinations of these three solvents.

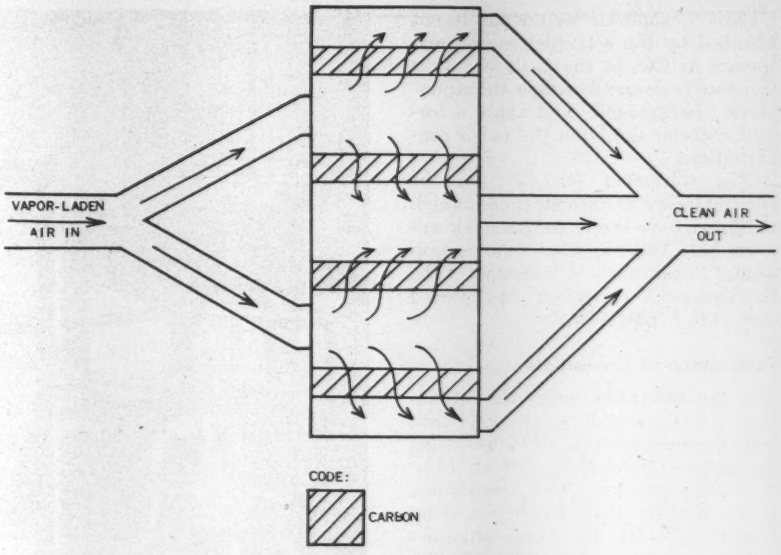


Fig. 6. Proposed fixed bed adsorber.

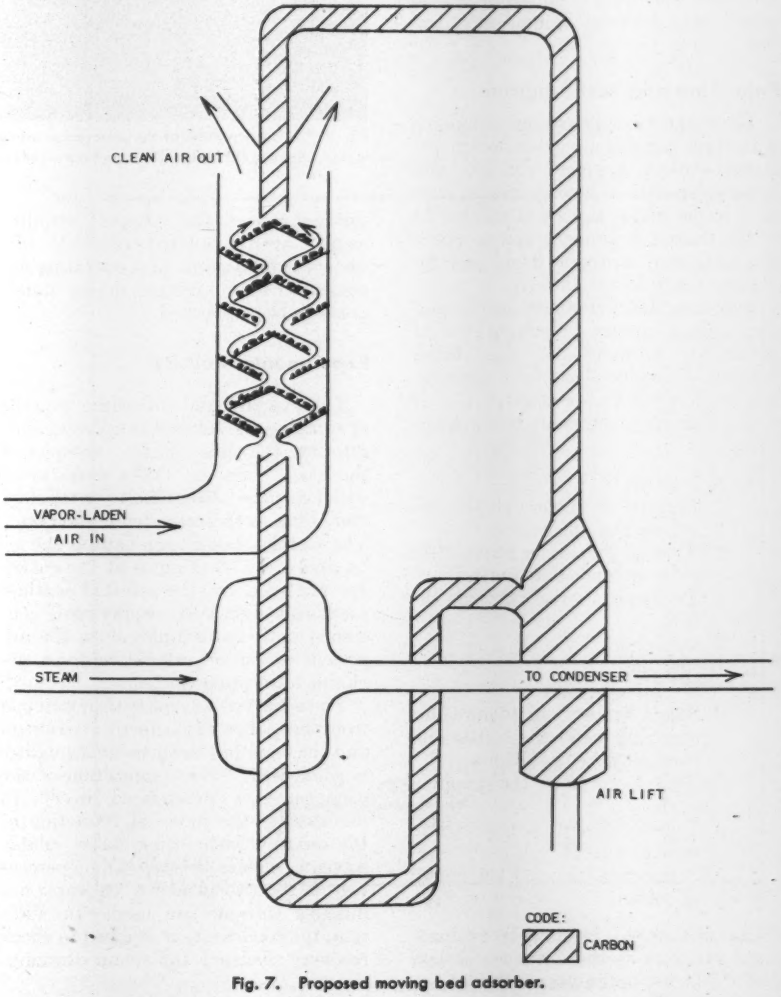


Fig. 7. Proposed moving bed adsorber.

Carbon monoxide in the air is not adsorbed by the activated carbon and appears as CO_2 in the analysis. It is therefore necessary to sample the atmospheric "background" and apply a correction factor to obtain the vapor concentrations.

This correction for CO can be appreciable. CO concentrations as high as 72 ppm have been recorded in Downtown Los Angeles, where the experimental equipment is located. The "background" correction has varied from 11 to 22 ppm CO_2.

Composition of Condensate

In the desorption cycle, the estimation of water soluble polar compounds in the condensate is made by determining the index of refraction with an Abbe type refractometer. The composition of the mixture is then determined by comparison with the composition-refractive index curve for the particular mixture.

The composition of toluene-mineral spirits mixtures is determined by the specific gravity of the mixture. These solvents have additive volumes, and the relationship between volume and density is linear.

Paint Spraying Test Program

The initial testing has been completed with three commercial grade solvents—methyl ethyl ketone, toluene, and mineral spirits. These solvents were used to determine rates and efficiencies of the control equipment and to check the analytical methods developed for organic spray booth effluents.

Following this preliminary work, complex solvent mixtures representative of industrial formulations are being sprayed. Finally—lacquers, enamels, and primers will be investigated.

The following factors are being determined:

A. Adsorption
   1. Pressure drop through the bed
   2. Adsorption efficiency
   3. Type of precleaner required to remove particulate matter
   4. Temperature rise through the bed
   5. Carbon life

B. Desorption
   1. Overall efficiency
   2. Steam temperature required for stripping various solvents and combinations of solvents
   3. Time required for the stripping cycle
   4. Type of operation required to recover solvent
   5. Steam requirements per pound of solvent

These factors will be used to evaluate such variables as the optimum carbon bed thickness, optimum number of adsorbing vessels, the stripping requirements, overall solvent recovery efficiency, capital costs, and operating expenses, so that optimum design standards can be established.

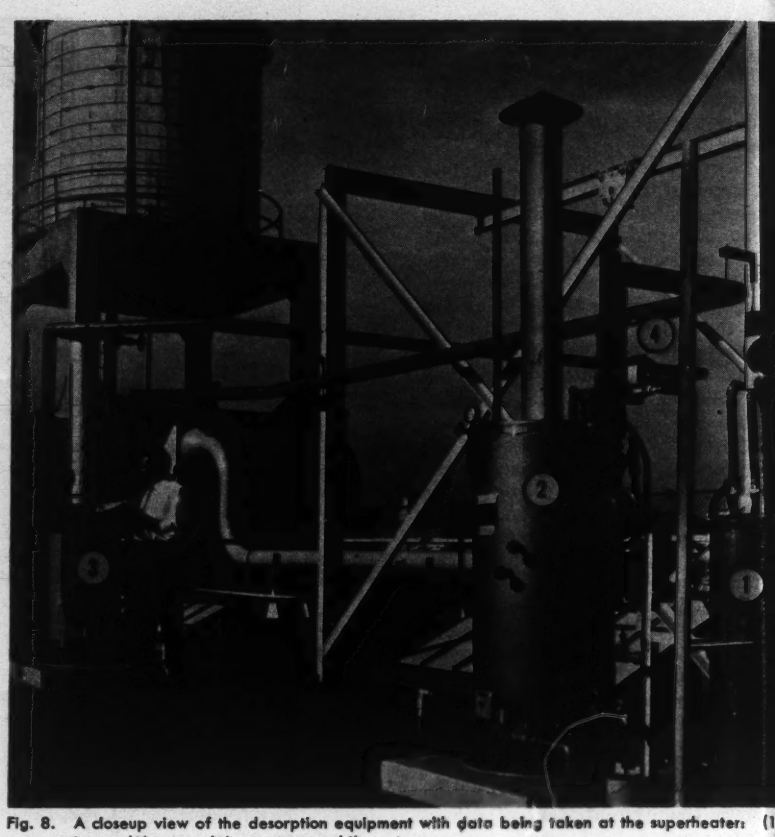


Fig. 8. A closeup view of the desorption equipment with data being taken at the superheater: (1) water softener; (2) boiler; (3) superheater; (4) condenser.

Experimental Results

The experimental procedure consists of spraying the solvent at a known flow rate into the spray booth. Samples of the gas stream are taken periodically with evacuated 250-ml bulbs at the inlet and outlet of the activated carbon unit. The samples, taken each hour at the inlet and every 30 minutes at the outlet, are analyzed by the infrared method previously discussed. Spraying is continued until the samples show the approach of carbon saturation by a declining adsorption efficiency.

The adsorbed solvent is then stripped from the carbon with superheated steam and the resulting steam-solvent mixture is condensed. The composition of the condensate is determined every 15 minutes by the index of refraction of the mixture when using water soluble solvents, and/or by the volume percentage of the two phases when water immiscible solvents are used. In addition, the condensate is weighed to check recovery efficiency and steam consumption.

Adsorption Results

The pressure drop through the carbon bed during adsorption is 0.21 in. of water at a flow rate of 1350 cfm. This is considerably less than the predicted design resistance of the bed, 0.45 in. of water, and indicates the conical configuration of the bed may be of economic significance. The empirical formula for the conical bed resistance, derived from experimental results, is

$$\Delta P = 0.33D \left(\frac{V}{100}\right)^{1.66}$$

where

ΔP = pressure drop, inches of water
D = carbon bed depth, inches
V = air velocity, fpm

No significant temperature rise across the carbon bed has been observed. Calculations based on the maximum toluene concentration of 150 ppm indicate that the heat of adsorption is 18 Btu/min, resulting in an air temperature rise of 0.7°F. The equipment is operated at ambient air temperature, varying from 52 to 95°F.

Single Solvents

Sixteen complete adsorption-desorption cycles were made—four with methyl ethyl ketone (MEK), eight with

toluene, and four with aliphatic mineral spirits. The solvent concentration entering the activated carbon unit varied from 100 to 150 ppm.

The dry air filters were used to remove any particulate matter during all runs. In addition, the water wash curtain was used at a rate of 90 gpm during two of the MEK runs.

The MEK content of the circulating water was determined throughout these runs. The amount of MEK absorbed by the water curtain was negligible because of the short contact time and the low vapor concentration which results in a negligible absorption driving force.

The adsorption efficiencies, prior to reaching the adsorption "break point," were high for all runs. Typical adsorption efficiency curves are shown in Fig. 9. The average adsorption efficiencies for the 16 runs are summarized in Table I.

The increased efficiency of the toluene and mineral spirits runs is the result of more homogeneous carbon packing. The adsorbing cone was repacked to eliminate several voids through which solvent was escaping.

The validity of the infrared analytical method was confirmed during the adsorption runs. For example, eight MEK inlet samples taken during a four-hour period indicated an average concentration of 96 ppm. The calculated concentration, based on the quantity of solvent sprayed was 98 ppm. Accurate determinations, such as these, were made on all runs.

Complex Solvent Mixtures

Following the preliminary work with single solvents, a complex solvent mixture representative of industrial formulations was investigated. Three runs have been made with a pseudo lacquer solvent containing 50 percent toluene. 37.5 percent MEK, and 12.5 percent mineral spirits. The solvent concentration was varied from 75 to 170 ppm with an air flow of 1350 cfm.

The adsorption efficiency using the pseudo lacquer solvent averaged 98 percent until the first "break point" was reached. Several equilibrium break points occur with complex mixtures as shown by Fig. 10.

Fractionation occurs as low boiling, low molecular weight compounds are displaced from the carbon by less volatile solvent constituents. A material

Table I—Absorption Efficiencies for Single Solvents

Solvent	Average Efficiency to "Break Point," %
MEK (4 runs)	93
Toluene (8 runs)	97
Mineral spirits (4 runs)	96

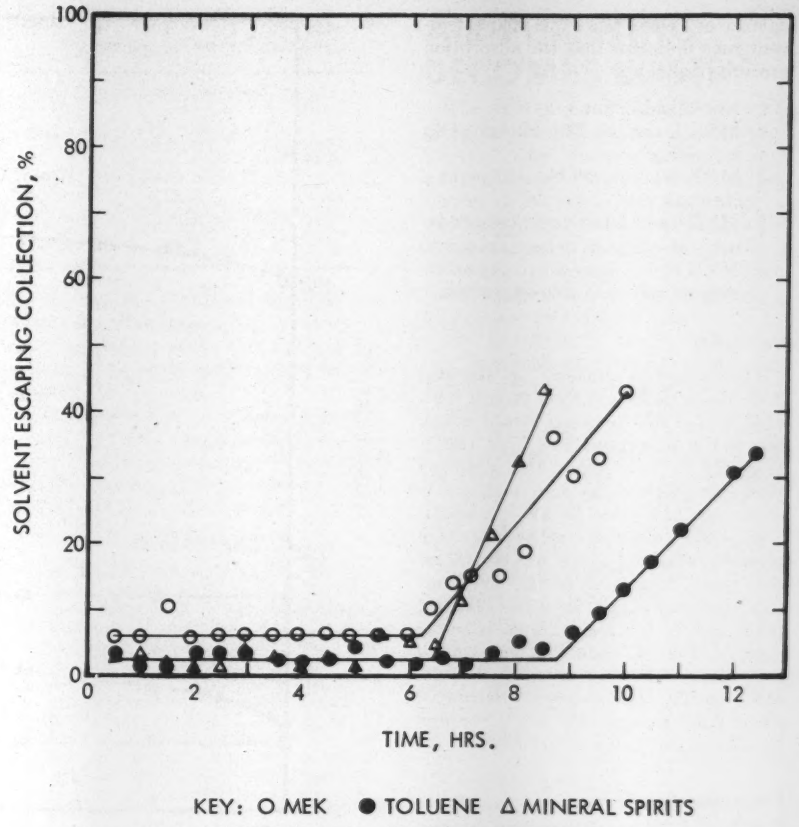


Fig. 9. Adsorption efficiency, single solvents.

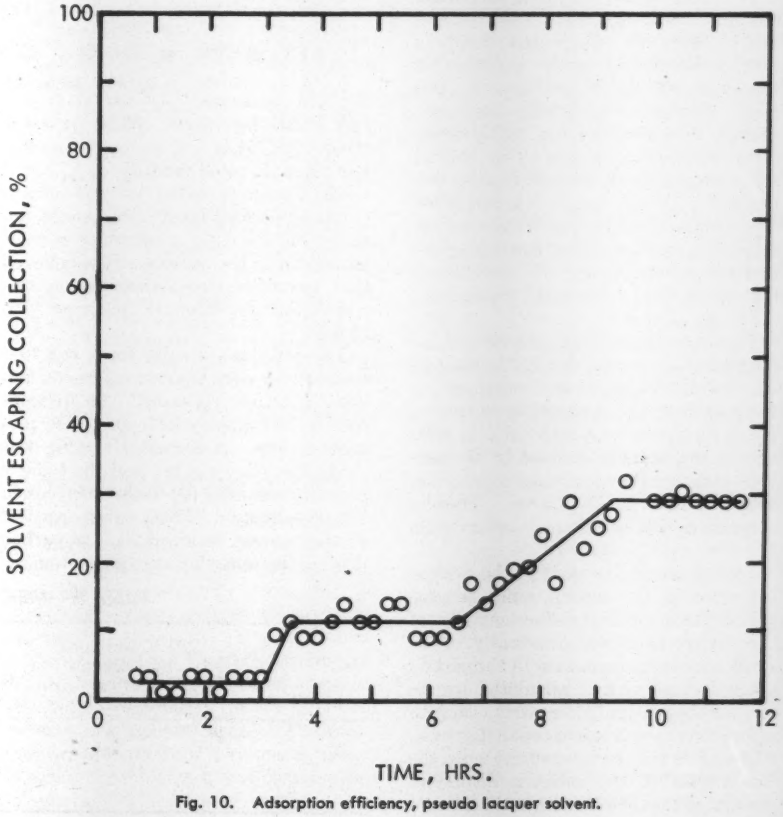


Fig. 10. Adsorption efficiency, pseudo lacquer solvent.

balance of each of the three lacquer solvent runs indicates that the adsorption proceeds as follows:

1 Normal adsorption
2 MEK is displaced by toluene at an increasing rate
3 MEK is displaced by toluene at a constant rate
4 MEK and toluene are displaced by mineral spirits at an increasing rate
5 MEK and toluene are displaced by mineral spirits at a constant rate

Desorption

The adsorbed solvent is stripped from the activated carbon in situ with superheated low pressure steam which enters the adsorbing vessel at 650°F and one to two psig. The resulting steam-revaporized solvent mixture is condensed in a small helical condenser.

Superheated steam, rather than high pressure saturated steam, was chosen for the experimental work so that low pressure equipment could be used. Boiling point curves for the various solvents sprayed (Fig. 11) show that a minimum temperature of 406°F is required to desorb spirits completely. Saturated steam condensing at 250 psig is required to achieve this temperature level.

Desorption Results— Single Solvents

The first steam stripping of MEK was done with saturated steam at two to five psig; all subsequent stripping was accomplished with superheated steam at 600–650°F and one to two psig. The initial condensate contained slightly over two percent MEK when using saturated steam. This initial concentration was increased to six-seven percent with the use of superheated steam. In all cases the MEK content dropped to two percent or less during the first hour of stripping. The MEK content of the total condensate varied from 2.3 to 3.5 percent.

The stripping of the carbon was incomplete, and a considerable amount of the solvent apparently remained in the carbon. The desorption efficiency, based on the solvent recovered in relation to the amount retained by the carbon during the spraying operation, varied from 41 to 82 percent. The desorption results are summarized in Table II.

It is assumed that part of the solvent remained in the carbon, since the experimentally determined retentivity of the carbon decreased constantly. The residual solvent remaining in the carbon after desorption was calculated by assuming that the only losses from the system are the solvent recovered in the condensate and the solvent lost when the air initially in the vessel is displaced. Assuming that the air within the adsorption vessel leaves the condenser saturated with MEK and water vapor, this loss amounts to only 0.9 lb.

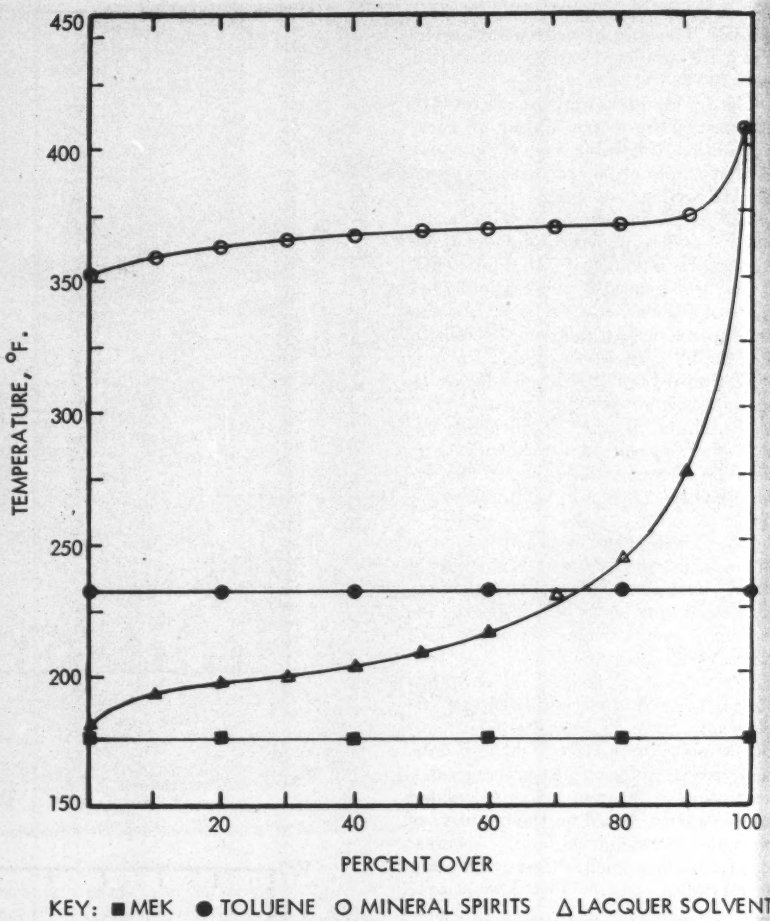


Fig. 11. Engler distillation curves for solvents.

The hysteresis effect inferent to adsorption—desorption cycles cannot account for the large amount of solvent remaining in the carbon. It is believed that improper steam distribution was responsible for the low recovery efficiency.

The stripping results from the first toluene run were similar. The condensate initially contained 24 percent toluene but quickly dropped to five percent or less. A second stripping was made the following day and the toluene recovery was only 0.4 weight percent of the condensate. Forty-seven percent of the toluene retained by the carbon during the spraying operation was recovered. The index of refraction of the toluene contaminated water in the condensate indicated that slightly less than one per cent of the condensate was methyl ethyl ketone.

A number of modifications were made to improve the steam distribution, reduce heat losses, and increase the steam supplied to the adsorber. The desorption efficiency for the remaining seven toluene runs averaged 97 percent. The maximum inlet temperature for these runs varied from 420 to 470°F; the discharge temperature varied from 312 to 380°F.

Higher temperatures were required to effectively desorb mineral spirits; the inlet temperature range was 490 to 521°F. The average stripping efficiency for mineral spirits was 92 percent.

Table II—MEK Desorption Results

Run No.	MEK Retained by Carbon During Spraying, Lb	MEK Recovered, Lb	Recovery Efficiency, %	MEK in Carbon After Stripping, Lb
1	31.4	12.9	41	16.7
2	21.9	17.9	82	18.9
3	15.7	10.0	64	22.6
4	14.7	9.4	64	27.2

Desorption Results—Complex Solvents

The desorption efficiency, based on the solvent recovered in relation to the amount retained by the carbon during the adsorption period, averaged 94.5 percent for the three runs made to date. The inlet temperature for these runs was maintained at 520°F. This resulted in maximum discharge temperatures of 406 to 419°F.

The desorption efficiency, based on the amount of solvent sprayed, rather than the amount retained by the carbon, is interesting. More mineral spirits was recovered on each run than was sprayed during the adsorption cycle. The recovery of each component is shown in Table III. This indicates that the desorption of the higher boiling fractions of mineral spirits during the preceding runs was incomplete and that some of this material was recovered during the subsequent lacquer solvent runs. The apparently low recovery efficiency for MEK resulted because a considerable quantity of this solvent was displaced from the carbon by higher boiling solvents during the adsorption period.

An average of 25 lb of superheated steam at 650°F and one to two psig has been required for each pound of solvent recovered. This is thermally equivalent to 4.7 lb of saturated steam at 250 psig/lb of solvent.

Solvent Recovery

An attempt was made to recover MEK by salting out the condensate with sodium chloride. A negligible amount of MEK was recovered. It is planned to investigate recovery by distillation.

Mineral spirits and toluene, being immiscible with water, are recovered by simple decantation for reuse.

Carbon Life

The adsorber has operated a total of 376 hours, 204 of which were during the adsorption phase. A slight decline in the retentivity of the activated carbon has been observed. It is not known at the present time if this is due to incomplete desorption or whether the carbon is being slowly deactivated.

Conclusions

The control of organic emissions from surface coating operations by adsorption with activated carbon is technically feasible. Single solvents or combinations of solvents in low concentrations are adsorbed and recovered with high overall efficiency.

The experimental work is continuing to obtain sufficient data to evaluate the economic feasibility of this control method. Future work will include the investigation of other solvent mixtures and surface coatings, determination of particulate matter removal requirements, the investigation of alternate adsorption vessel designs, the recovery of water soluble solvents, and methods for reducing the steam consumption for desorption.

The desorption of mineral spirits appear to be the most formidable economic factor as the required desorption temperature level is high and the value of the recovered solvent is low.

Table III—Desorption Results for Complex Solvent Mixtures

	Recovery Efficiency, %		
	Mineral Spirits	Toluene	MEK
Run 1	126.5	86.5	30.0
Run 2	118.2	84.9	69.8
Run 3	117.0	92.0	36.4
Average	120.6	87.8	45.4

REFERENCES

1. R. G. Lunche, A. Stein, C. F. Seymour and R. L. Weimer, "Distribution Survey of Products Emitting Organic Vapors in Los Angeles County," *Chemical Engineering Progress*, **53**, 371–376 (August, 1957).
2. Air Pollution Control District, County of Los Angeles. Unpublished data.
3. E. F. Spencer, Jr., N. Kayne, M. F. LeDuc, and J. H. Elliott, An Evaluation of Methods for the Control of Organic Emissions from Protective Coating Spraying Operations. Air Pollution Control District, County of Los Angeles (July 1, 1958).
4. L. Scheflan and M. B. Jacobs, The Handbook of Solvents. D. Van Nostrand Company, New York (1953).
5. A. B. Ray," Recovery of Solvent Vapors," *Chemical and Metallurgical Engineering*, **47**, 329–332 (1940).
6. C. L. Mantell, Adsorption, McGraw-Hill Book Company, New York (1951).
7. R. Merims, *Chemical Engineering*, **59**, 162 (October 1952).
8. C. L. Mantell, *Op. Cit.*, p. 240.
9. T. M. Browning, "Adsorption: Vapor Phase Systems Serve Industry Well," *Chemical Engineering*, **59**, 158–161 (October 1952).
10. A. B. Ray, *Op. Cit.*, p. 332.
11. R. Goldstein, J. Gliksman and J. H. Elliott, "A Combustion Method for the Determination of Solvent Vapors at Low Concentrations in Air." Paper presented at the 52nd Annual Meeting, Air Pollution Control Association, Los Angeles, California (June 1959).

CONFERENCE HELD

The University of California School of Medicine and U. C. Extension presented a three-day conference on "Man and His Environment: The Air He Breathes" January 16–18 in San Francisco.

According to University officials, "The Conference emphasized a multidisciplinary approach to the problems of man in his environment. The meeting was designed for physicians, physiologists, pathologists, ecologists, town planners, engineers and others. The problems were considered from the widest biologic point of view."

AIR PURIFYING BECOMES COSTLY

The nine phosphate companies operating in the Polk-East Hillsborough County area, Florida, have invested more than $11,000,000 to date in research, development and installation of waste control systems to purify air and water released from their plants, a phosphate company research engineer told a statewide meeting of industrial waste experts recently.

Dr. Randolph C. Specht, the American Agricultural Chemical Company, Pierce, reported the figure in a paper presented before the industrial wastes technical session of the Florida Sewage and Industrial Wastes Association and the Florida section of the American Water Works Association, in joint session. His subject was "Disposal of Wastes from the Phosphate Industry."

Also on the program were Dr. E. R. Hendrickson, Gainesville, chairman of the Florida Air Pollution Control Commission and an APCA member; B. Clarke Nichols, Tallahassee, assistant state attorney general and former legal counsel for the air pollution control commission, and Dr. Robert O. Vernon, Tallahassee, director of the Geological Survey.

The rapid progress being made in science and industry, Dr. Specht said, "presents a challange to manufacturing agencies."

"As population increased and towns grew into cities, waste disposal, industrial and municipal, became more of a problem. Because of a desire by industry and its neighbors to live together, these problems of pollution have been studied and progress has been made."

The total investment in the waste control program includes $6,737,221 to purify air, the research expert said, and $4,605,202 to remove impurities from water.

During washing, sizing and other phosphate plant processes, Dr. Specht said, clear water is introduced and waste water removed at several points. The waste water is routed to large separators or settling areas where the clay and sand settle, leaving clear water which is recycled for use in the plant processes.

These settling areas also act as a reservoir for collecting rain water during the rainy season.

Topics for consideration included "The 'Normal' Atmosphere and Its Variation;" "The Air Pollution Problem of Industry;" "Urban Living and Air Pollution;" and such specific problems as "Airborne Factors in Cancer."

RADIOLOGICAL PROGRAM of the Los Angeles County Air Pollution Control District*

ADAM WILEY, Radiological Co-ordinator, and **PHILIP S. TOW,**
Senior Research Assistant, Los Angeles County Air Pollution Control District

Man has always been exposed to a natural background of radiation from cosmic rays and naturally occurring radioactive substances in his environment. Since the beginning of the twentieth century, there has been an ever-increasing number of sources which are responsible for adding air-borne radioactivity to the natural background. The most important sources are in the fields of industry, medicine, research, and nuclear weapon tests. Of these, radioactive wastes from industry and fallout from nuclear weapon tests have been the most important causes for increases in air-borne radioactivity.

Sources of industrial radioactive wastes are nuclear reactors or large chemical processing plants which may periodically remove fission product gases, laboratories which may necessarily vent radioactive materials, and the incineration of radioactive solid wastes which contribute gaseous products to the atmosphere.

Fallout from nuclear weapon tests may cause increases in levels of air-borne radioactivity in several ways. The fallout may come from the radioactive "cloud" which is carried by winds through the troposphere, or lower atmosphere, or from the radioactive "cloud" in the stratosphere. Fallout occurring relatively soon after nuclear tests and in areas adjacent to the nuclear tests, or within a few hundred miles of them, is from the radioactive cloud in the troposphere. Slow fallout from the stratosphere occurs over a period of a few years and deposits mainly long-lived radioactive fission products which have been injected into the stratosphere by the energy of the explosion. The extent and rate of fallout may vary within any given area depending primarily on the distances from the explosion, radius and height of the cloud, particle size distribution, fall velocities, and local topographical and meteorological conditions.

In the past, significant increases in levels of air-borne radioactivity in the Los Angeles area have been attributed to fallout. The highest level detected thus far in the Los Angeles area approached, for a period of a few hours, the maximum permissible concentration in air as recommended in the National Bureau of Standards Handbook, 52.[1] This high level was attributed to fallout from the 1958 series of nuclear weapon tests in Nevada (Fig. 1).

The possibility of a nuclear weapons attack on this country has accelerated radiological disaster planning and organization at all levels of government. To cope effectively with such a disaster requires a trained force of personnel fully qualified and equipped to monitor radiation intensities and to provide advice on decontamination procedures for personnel, property, water supplies and land areas. This need has resulted in the organization of the Radiological Defense and Disaster Service as an important segment of the Los Angeles County Disaster-Civil Defense Authority which forms a part of the state and federal civil defense structure.

Responsibilities of the Air Pollution Control District

The Los Angeles County Air Pollution Control District is concerned with potential radiation and radioactivity problems in two respects:

1 Since air-borne radioactive material may be considered as air pollution within the meaning of the California State Health and Safety Code, the Rules and Regulations of the Air Pollution Control District apply to potential sources of such material.

2 The Air Pollution Control District has been assigned the responsibility of providing radiological monitoring services within the County during a declared disaster.

The term "air-borne radioactive material," as defined by the Rules and Regulations of the Air Pollution Control District, is any radioactive material dispersed in the air in the form of dusts, fumes, mists, smoke, liquids, vapors, or gases. Responsibility is not considered to extend to control of the use of ionizing radiation-producing devices such as X-ray machines, or to the use of isotopes where there is no actual or potential emission of air-borne radioactive materials.

The Air Pollution Control District has obtained and evaluated such pertinent data and other information bearing on the potential problems of radioactivity as have been released by the Atomic Energy Commission and other organizations conducting programs of research in this general field. This research has provided data which can be integrated into local air pollution control programs to afford maximum protection to the public. The data has been evaluated in the light of local problems and experiences.

It is known, for instance, that the meteorological factors contributing to the formation of a smog complex in Los Angeles are also important in considering potential problems which might arise from air-borne radioactive substances. As in the case of other air contaminants, radioactive material emitted into the atmosphere can be accumulated as a result of frequent and persistent low inversion layers and weak and variable wind movements. These two meteorological phenomena restrict the dilution and dispersal of any material emitted into the air above Los Angeles County. Since some of the radioactive materials which may be

* Presented at the 52nd Annual Meeting of APCA, Statler Hotel, June 21–26 1959, Los Angeles, California.

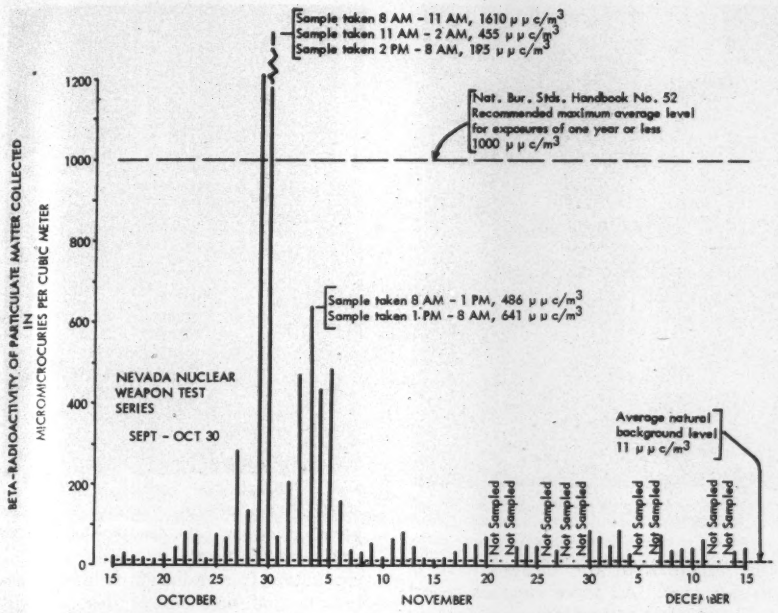


Fig. 1. Beta-radioactivity of airborne particulate matter collected at Burbank, California, from October 15, 1958—December 15, 1958. Samples were taken over a 24-hour period (8 A M on day shown to 8 A M of next day) and measured for β-activity one hour after sampling was completed.

added to the Los Angeles atmosphere are several orders of magnitude more toxic than the substances commonly contributing to smog, it has become extremely important that the Air Pollution Control District monitor closely the levels of air-borne radioactivity and require control of sources of emissions of radioactive material.

Implementation of the Control Program

Currently, implementation of the radiological control program is being carried out in three interrelated phases:

1 Determination of sources (or potential sources) of air-borne radioactive materials and instigation of efficient control methods.

Fig. 2. Fiberglas filter being mounted in the sampling head of a Staplex high volume air sampler.

2 Determination of the factors which would affect the dispersal of radioactive material throughout Los Angeles County.

3 Detection and measurement of the concentrations of radioactive materials in the atmosphere.

In determining the sources of potential radioactive emissions within Los Angeles County, the Air Pollution Control District has used two avenues of approach. Since Atomic Energy Commission licenses are required for users of most radioactive materials, such as by-product, special nuclear and source materials, a list of all agencies requiring such licenses has been obtained.

In addition, a record of users of radioactive materials such as radium and other non-reactor produced isotopes, who are not required to obtain an AEC license, is compiled by listing names of companies and agencies who apply for authority to construct or permit to operate certain equipment which may use these materials.

Since local meteorological and topographical factors influence the dispersion and concentration of air-borne radioactive material, the study by the Air Pollution Control District of the meteorology of the Los Angeles Basin has been particularly valuable. Extensive studies of wind velocities and movements have resulted in the development of data which contribute materially to effective decisions regarding possible radiological control measures, including possible restrictions on site locations for possible sources of radioactive emissions.

Routine Monitoring of Air-Borne Radioactivity

The Air Pollution Control District monitors the atmosphere on a continuous basis for concentrations of air-borne radioactivity. In the past, significant increases in the air-borne radioactivity levels in the Los Angeles area have been due to fallout from nuclear weapon tests conducted throughout the world. Because of this, other agencies are also independently monitoring air-borne radioactivity. These include the State Health Department, the Los Angeles County Health Department, the Los Angeles City Health Department, and the Atomic Energy Commission Project at UCLA. As the result of such overlapping interests, it was agreed that data on measured increases of radioactivity levels which equal or exceed five times the normal background would be exchanged among the monitoring agencies.

The air-borne radioactivity sample collection apparatus used by the Air Pollution Control District consists of a Staplex high volume air sampler with an 8 in. x 10 in. fiberglas filter

Fig. 3. Proportional gas flow counter, (left) decade scaler (center) and cylinders of an argon-methane mixture used during the counting procedure.

Fig. 4. Radiometer and recorder for continuous measuring and recording of ambie gamma radiation. The ion chamber can b seen above the cabinet.

mounted in the sampling head (Fig. 2). Particulate matter is collected by drawing a known volume of air through the filter. The counting equipment used to determine the level of radioactivity from the sample collected consists of a proportional gas flow counter and a scaler (Fig. 3).

The Air Pollution Control District also has an ion chamber type instrument (Fig. 4) for continuous monitoring of ambient gamma radiation. This radiometer records the integrated readings on a chart in milliroentgens per hour.

Radiological Defense and Disaster Program

The possibility of a nuclear weapons attack on this country has become a serious concern of all levels of government. To assure effective action at local levels in the event of such an attack, the State of California has been divided into three Mutual Aid Regions, each with its own central and subordinate organizations.

Located within Region One is the Los Angeles County Disaster-Civil Defense Authority and its seven subordinate Mutual Aid Districts. Under provisions of Los Angeles County Ordinance 5582, the Air Pollution Control District has been declared the Radiological Defense and Disaster Service which bears the responsibility for providing radiological monitoring services for the Los Angeles County Disaster-Civil Defense Authority.

Designed to make maximum use of the total resources in any given area and to assure effective action in common geographic areas encompassing several political jurisdictions, the overall organization structure is like a pyramid. At the base are the Mutual Aid Districts reporting to the County Disaster-Civil Defense Authority which, in turn, reports to the headquarters of Region One. All three Regions report to the State Disaster Office in order that a composite state-wide evaluation may be made.

To develop a capability for meeting this assignment of responsibility, the Air Pollution Control District has implemented a program which includes:

1 Conducting 16-hour radiological meter operator courses to train all Air Pollution Control District personnel as well as other County Service personnel.
2 Procuring and distributing radiation survey instruments throughout the area of responsibility.
3 Preparing plans of action for war-caused or peacetime radiological disasters.
4 Conducting quarterly radiological defense training exercises.

Disaster Monitoring Training

The 16-hour radiological meter operator course is designed to provide personnel with a basic understanding of ionizing radiation and its hazards, to develop skill in the use of radiation survey instruments, and to develop knowledge of operating and communication procedures within the civil defense structure. The course includes both classroom and field instructions.

Each class is usually held to a maximum of 25 students. There are 12 hours of classroom lectures, given by a group of instructors in the subjects of basic concepts of nuclear radiation, principles and measurement of radiation detection, biological effects and maximum permissible exposures, effects of nuclear weapons, protection against fallout, graphic and rule-of-thumb methods of computing dose rate and dose, survey instrument familiarization, monitoring techniques, introduction to a radiation field, contam ination and methods of decontamina tion. More than 300 of the Distric personnel have completed this course.

The four-hour field exercise include practice in communication procedure and area, automobile, and personn monitoring techniques. The class i divided into four teams whereby eac team, in rotation, has an opportunit to participate as a control center staf a field monitoring team (Fig. 5), and a automobile and personnel monitorin team. In one phase of the monitorin exercise, several 100-millicurie cobalt 60 sources are placed in a predetermine pattern in an open field in order t establish irregularly shaped iso-inten sity lines. Radioactive sources are als placed at various locations in cars an dummies to simulate contamination.

Trainees manning the control cente by use of "handie-talkie" radiotele phone communications, direct the fiel monitoring team operations and receiv information on the levels of radiatio in order to determine iso-intensit lines. The automobile and the per sonnel monitoring teams determine wha automobiles and personnel are in nee of decontamination.

Monitoring Equipment

The Air Pollution Control Distric has, through its own purchases an through loans from the State of Cali fornia Disaster Office, procured in struments which have been distribute throughout its geographical area o responsibility. Each of the approxi mately 80 enforcement patrol vehicles equipped with two-way mobile radio have been provided with an ion cham ber, a pocket dosimeter, a radiatio dosage calculator, respiratory mask gridded maps, and necessary monitor ing forms. Approximately 35 of thes vehicles are also equipped with Geige

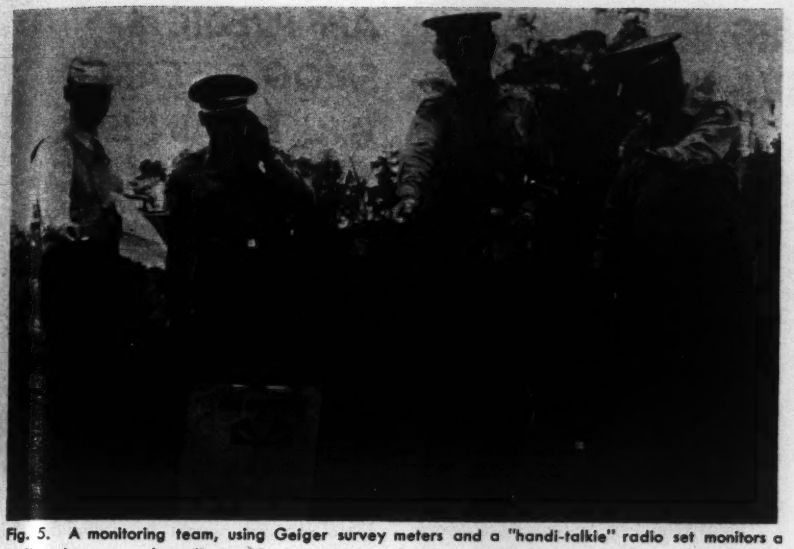


Fig. 5. A monitoring team, using Geiger survey meters and a "handi-talkie" radio set monitors a radioactive area. In a disaster, less sensitive ion chamber meters would probably be used for area monitoring.

survey meters.

Inspectors normally operate these vehicles in well-dispersed locations in the heavily populated portion of the County and are expected to provide the framework for the radiological service because of their mobility and communication capability, and are expected to provide the initial information on levels of radiation intensity should an enemy attack occur.

Nine radiological meter operator monitoring kits, each containing a number of survey instruments and other equipment, have been distributed to nine County Civil Defense Mutual Aid District headquarters in the outlying areas of Los Angeles County to be used by Air Pollution Control District personnel. A State-owned mobile radiological laboratory (Fig. 6), operated by the Air Pollution Control District, is designed to provide radioassay and emergency service wherever and whenever required. The California Disaster Office has also made available, to certain hospitals and high schools throughout the State, a substantial number of radiological monitoring kits.

A war-caused disaster plan is included as one of the Air Pollution Control District Administrative Procedures, a copy of which each employee is required to have on hand and understand. The essential elements of the plan are that, time permitting, employees are to evacuate to suburban areas beyond a 20 mile radius from the Los Angeles Civic Center before an attack. Following an attack, employees are then directed to report to the Mutual Aid District Headquarters nearest their home as soon as practicable. The peacetime disaster plan is more general in nature allowing flexibility of plans to best meet the needs of a particular situation.

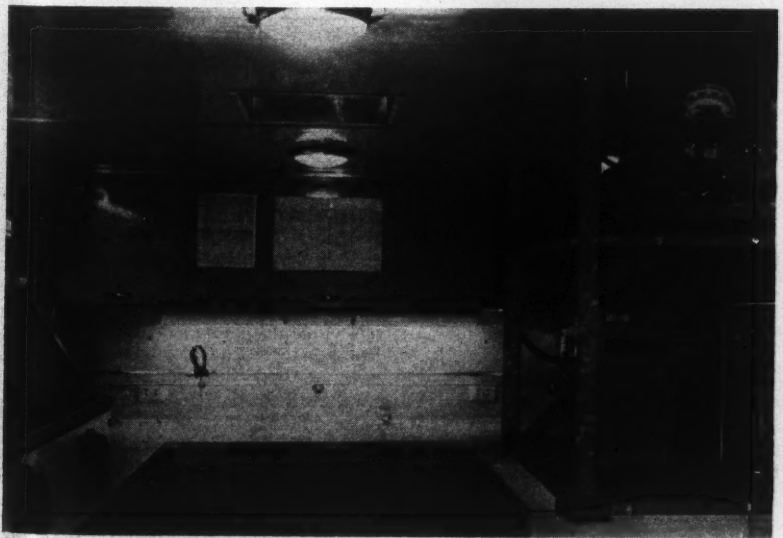


Fig. 6. Inside view of the mobile radiological laboratory looking toward the rear of the truck. At right are the scintillation counter and two scalers.

The purpose of a quarterly radiological defense exercise, utilizing the Air Pollution Control District communications network and radio-equipped enforcement patrol vehicles, is to verify the ability of the monitors to give accurate survey meter readings, determine locations on a map by use of the grid system and to report this information in accordance with established communication procedures, and to verify the ability of the control center personnel to occupy any one of a number of positions that may require staffing during an emergency.

Conclusions

The role of the Air Pollution Control District during declared disasters has been clearly established by statutes. It is impossible to predict the severity of a war-caused disaster or even the response of any group charged with alleviation of disaster effects. A responsible organization, well trained and equipped, must be able to respond to aid the general population in any disaster, and may thereby be an important factor in saving the lives of hundreds of thousands of persons.

What constitutes proper training is a difficult question, when it is, of course, impossible to conduct training under realistic conditions. It is, however, believed that all Air Pollution Control District personnel assigned to a role in the overall disaster relief organization have been trained adequately in the mechanics of their assignments.

Responsibility of the Air Pollution Control District in monitoring and control of air-borne radioactivity asociated with situations of less than disaster proportions is less clear-cut. Fallout from nuclear weapon tests or from nuclear reactors located outside a particular county area cannot be controlled by agencies of that county. Fallout from weapon testing, up to now, has accounted for the preponderance of air-borne radioactivity in Los Angeles County. With increasing numbers of nuclear reactors and other sources of radioactivity, this condition may change. Thus, there is a need now for more precise regulations governing control of radioactive sources and a better delineation of responsibilities of the various governmental agencies.

REFERENCES

1. United States Department of Commerce, National Bureau of Standards, "Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water," Handbook 52, March 20, 1953.

DR. LEONARD GREENBURG RESIGNS POST; AFFILIATES WITH YESHIVA U. IN MEDICINE

Dr. Leonard Greenburg, President of APCA, resigned from his post as Commissioner of the New York City Department of Air Pollution Control January 8, to take a position as Professor and Acting Chairman of the Department of Preventive Medicine at the Albert Einstein College of Medicine, Yeshiva University, New York City. Dr. Greenburg has been Commissioner of the Department of Air Pollution Control since the establishment of the agency in November, 1952.

From 1918 to the present time, Dr. Greenburg has worked continuously in the field of public health and has contributed a large number of technical articles to the literature in this field.

While a member of the United States Public Health Service, in 1923, he was appointed a member of the Committee to investigate sanitary conditions at Ellis Island and their relation to the health of the immigrant. In 1924, he was in charge of the U. S. Public Health Service studies on ventilation of the U. S. Capitol Buildings, which resulted in the provision of air conditioning systems in both houses of Congress. In 1926, he visited Europe as a member of the U. S. Public Health Service for the purpose of making studies of working conditions in industrial establishments. As a member of the Committee to study cerebro-spinal meningitis in relation to conditions on shipboard, in 1931 he travelled throughout the Orient, including Japan, China and the Philippine Islands.

In 1922, while a member of the U. S. Public Health Service, Dr. Leonard Greenburg (with Mr. George W. Smith, of the U. S. Bureau of Mines) invented the impinger dust sampling apparatus, which is now the universally accepted standard method for atmospheric dust sampling, in connection with the study of dust hazards and their relation to pulmonary disease.

Over a period of many years, he has engaged in many broad studies in the field of health, including morbidity and mortality studies, vital statistics, health department administration and many other aspects of the public health field.

During the years 1934 and 1935, as Health Commissioner of the City of New Haven, Connecticut, Dr. Greenberg exercised complete administrative control over the Health Department of a city having a population of approximately 170,000 persons. Dr. Greenburg resigned from this position in order to become Executive Director of the Division of Industrial Hygiene and Safety Standards of the New York State Department of Labor. This office has jurisdiction of occupational disease control and health and safety standards in all of the factories in the State of New York.

In 1938, Dr. Greenburg represented the U. S. Department of Labor at the International Silicosis Conference held in Geneva, Switzerland.

In 1950, he attended the International Silicosis Conference at Sydney, Australia, as Chief of the American Delegation.

Dr. Greenburg remained Director of the New York State Department of Labor Division of Industrial Hygiene and Safety Standards until November, 1952, when he was appointed New York City's Commissioner of Air Pollution Control.

Two of the City's newspapers, the *New York Times* and the *World Telegram and Sun*, saw fit to editorialize Dr. Greenburg's resignation as Commissioner. These editorials are a fitting tribute to his accomplishments and ability in his chosen field.

Creditable Performance

(*World Telegram and Sun* December 18, 1959)

Dr. Leonard Greenberg, commissioner of air pollution control since the department was established seven years ago, is leaving to join the medical faculty at Yeshiva University. The city is losing a good man.

(*Continued on page 94*)

APF PREDICTS SMOG RESEARCH WILL END IN 1960

The Air Pollution Foundation predicts in its 1959 Annual Report that "completion of the scientific work necessary for an economic end to our smog problem is now within one year's reach."

Managing Director W. L. Faith cites legislative, industrial, and basic research advances in 1959 as the basis for this prediction.

Mr. Faith, also an APCA Director, explains in his report, "One year ago, in my report to the Trustees and contributors to the Air Pollution Foundation, I stated that two more years of basic research would be adequate to obtain the information necessary to solve Los Angeles' smog problem. One of these important years has passed, and I see no reason to revise my estimate; in fact, we can be more optimistic now than we were then."

To Solve Smog Problem

Dedicated to the solution of the smog problem, the Foundation was incorporated under the laws of the State of California in 1953. It is unique because it was never intended to be self-perpetuating. Upon completion of its work it is to be liquidated.

With the end of the Foundation's work in view, President Fred D. Fagg, Jr. says, ". . . the Foundation's Trustees have decided that 1960 shall be the final year for which we will raise operational funds and that the Foundation shall be dissolved thereafter upon conclusion of the staff's work."

CALENDAR

March 22	Third Air Pollution Research Seminar, New Orleans, Louisiana.
April 4–15	Training course on "Atmospheric and Source Sampling," R. A. Taft Sanitary Engineering Center, Cincinnati, Ohio.
April 25–29	Training course on "Analysis of Atmospheric Inorganics," same as above.
May 2–6	Training Course on "Analysis of Atmospheric Organics," same as above.
May 19–20	Postgraduate course "Effect of Air Pollution and Environment on Health," University of Wisconsin, Madison, Wisconsin.
May 22–26	**53rd APCA Annual Meeting, Netherland-Hilton Hotel, Cincinnati, Ohio.**
July 25–29	13th International Congress on Occupational Health, Waldorf-Astoria Hotel, New York City

LETTERS TO THE EDITOR

(Continued from page 16)

difference (i.e. in the number of favorable responses) in favor of the use of counteractants." Although Mr. Turk did not choose to report on this matter statistically, or otherwise, I also stated that "even when the recommended quantity of odor counteractant was used, the reaction of the odor panel was almost two to one that the odor was "unpleasant" or "objectionable." No amount of statistical manipulation of the "favorable responses," representing as they do only a little more than a third of the total body of data, serves as an excuse for ignoring the implications of the latter observation.

When Mr. Turk concluded that ". . . the use of counteractant improves the odor acceptability of the effluent . . . Reliability of this statement: 91–95%," did he recall that he had previously characterized his data in these terms: "possess semantic confusion," "grossly lack(s) precision," "are a course measure," "have serious limitations" and "are fraught with experimental peril?" How difficult it is to understand why Mr. Turk permits himself to manipulate such inadequate data to "prove" that the odor counteractant really "works!"

Speculation

One can only speculate on Mr. Turk's reasons for insisting on the use of a 9-point odor rating scale when a simple 2-point soale is all that is needed to determine individual acceptance or nonacceptance of a specific odor. Surely one possessing his interest in odor problems is aware of the wide usage of preference testing for determining odor acceptability.

To create an issue concerning the sufficiency of the data reported in my article can only have the effect of retarding interest in the field of odor research. All the limitations of the study were carefully pointed out in detail: that this was a pilot field study with limited objectives; that the principal reasons for publication were to provide information on a topic not adequately covered in the technical literature and to stimulate those who advocate this method to give us more and better information. If the best evidence that can be assembled to refute the implications of my pilot study are my own data, "re-warmed," it merely confirms my original contention that this method of odor control is not yet based on published proof acceptable to workers in the field of air pollution control. I, for one, would be delighted to have scientists conduct the careful odor studies among the general population that Mr. Turk recommends; this, essentially, is my thesis. At least, Mr. Turk and I agree on the very great need for more and better studies.

Sincerely yours,
MELVIN W. FIRST
Consulting & Research Engineer
Newton Highlands, Mass.

GEORGE G. RITCHIE WINS DISTINCTION AS APCA's LONGEST-STANDING MEMBER

(Editor's Note—The October APCA News *contained a request for nominations of the people who had been members of APCA longest. Your editors' search for the member who has been with APCA longest has ended. A brief biographical sketch of APCA's longest standing member follows.)*

George G. Ritchie, now Coal Traffic Manager-Engineering, Chesapeake and Ohio Railway Company, Richmond, Virginia, first attended an APCA annual meeting in 1921. At that time the organization's name was the Smoke Prevention Association.

Mr. Ritchie was the Chesapeake and Ohio official representative to the SPA meetings from 1924 to 1929. During the '30's he served as a member of numerous committees of the SPA, and in 1939 was elected first vice president of the organization.

George G. Ritchie

His election to this position was unprecedented in the history of the SPA. Prior to 1939 no railroader had been elected to this position. The by-laws stipulated that a Chief Smoke Inspector, or a person in direct charge of the Smoke Regulation Department of a large city, should be elected president of the Association. There was an unwritten law that the first vice president would be selected from the coal and/or general industry and the second vice president from the railroads.

In 1942, Mr. Ritchie was commissioned an officer in the Corps of Engineers, returning from service in 1945. He again became active in SPA committee work and took an active part in changing the by-laws and the name to APCA to embrace all air pollution problems.

"I felt there was an urgent need for an association of this character," he writes. "It would enable those responsible for polluting the atmosphere, the air pollution control engineers, scientists and other civic-minded members of society to devise ways and means to solve many problems."

He has regularly attended meetings when it was possible for him to do so.

"Since 1952," Mr. Ritchie says, "I haven't been as active in the work of the APCA, however this doesn't indicate lack of interest in air pollution problems. The APCA now covers a much wider scope of air pollution problems than its predecessor, the SPA.

"This is natural with changing times, and the emission of smoke from coal fired locomotives is a problem of the past. It is true automobiles and diesels present other problems, but these do not come under my jurisdiction."

Mr. Ritchie retired about two years ago as Chairman of the Executive Committee of the Coal Producer's Committee for Smoke Abatement. However, he is still active in the work of both the Executive and General Committees. He is also a member of the City of Richmond Air Pollution Control Consultation Board and a former member of the Appeals Board.

ANTHRACITE COAL HELPS IN AP FIGHT

Anthracite coal has become increasingly important in solving air pollution problems. In an article published by the Scranton, Pennsylvania *Times*, anthracite was described as "the only inherently smokeless fuel."

Several northeastern cities are using anthracite to fight air pollution. For example, in Providence, Rhode Island, handfired boilers are required by law to be fired with hard coal. Other cities which use it to fight air pollution are Elmira, Syracuse, Binghamton and Watertown, New York; Norwich, Connecticut; and Pittsburgh, Pennsylvania.

William G. Christy, consulting engineer and former chief of air pollution control, New York City, said recently in a speech at Lehigh University: "Of the fuels commonly used in this country, three may be considered 'smokeless' for all practical purposes. These are anthracite, coke and gas. It is possible to get smoke from burning gas, but in practical operation it so seldom happens that this fuel should be put on the list of smokeless fuels.

"Neither anthracite, nor coke, will smoke under any circumstances. The Anthracite Institute designed a boiler to burn anthracite without any combustion space whatever. Even under such conditions, there was no trouble with smoke."

GREENBURG RESIGNS

(*Continued from page 92*)

We hope Mayor Wagner can find a successor with both the high ability and deep concern Dr. Greenburg has shown.

Incidentally, one of the most unsound suggestions we've heard lately was Councilman Stanley M. Isaacs' call for abolishing the Department of Air Pollution Control as an economy measure. The Health Department could take on this work, he said.

For one thing, that would tend to blur the problem. For another, the Health Department would have to hire at least as many field investigators and office personnel to do the job right. And probably more—because Dr. Greenburg is a man of economy.

The fact is that, far from rating abolition, what the department needs is more funds, both for enforcement and research. This is no paper-shuffling exercise Mr. Isaacs is talking about. It's a city agency dedicated to the extremely vital job of safeguarding New Yorkers' health, particularly their respiratory tracts, from the discomforts, illnesses and even deaths that runaway air pollution can inflict.

The Smoke Fighter Goes

(*New York Times* December 19, 1959)

The very name "Department of Air Pollution Control" suggests that success in the fight against smoke in a large city is certain to be relative rather than absolute. So Dr. Leonard Greenburg, resigning after seven years as Commissioner of New York's department, would not as a modest man claim anything like complete success. In fact, with respect to sootfall per square mile—one of the not wholly satisfactory measurements of air pollution—the city is dirtier than when he took over in 1952. By other yardsticks, such as gases, the city has held its own fairly well, except on automobile exhaust.

Nevertheless, it may be fairly said

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MAPPA HOLDS ANNUAL MEETING

MAPPA RE-ELECTS OFFICERS—Pictured here with Arnold Arch, luncheon speaker at MAPPA's December 16th, 1959 meeting in Chicago, are the re-elected officers of MAPPA. They are from left: Dr. C. E. Barthel, Jr., secretary; Douglas R. Fuller, Treasurer; Mr. Arch; and Dr. H. A. Leedy, president.

* * *

Dr. Haldon A. Leedy, director of Armour Research Foundation of Illinois Institute of Technology, was re-elected president of the Midwest Air Pollution Prevention Association, Incorporated, at the group's annual meeting December 16 in Chicago.

Other officers re-elected were Lewis A. Evans, Chicago and Indiana Railroad Company, first vice president; Dan A. Sullivan, consultant at Armour Research Foundation, second vice president; Douglas R. Fuller, Northern Trust Company, treasurer; and Dr. Christopher E. Barthel, Jr., assistant director of ARF, secretary.

Elected to the board of directors for three-year terms were Raymond T. Host, Joseph Goder Incinerators; Raymond D. Maxson, Commonwealth Edison; Erwin E. Schulze, of the law firm of Stevenson, Conaghan, Hackbert, Rooks and Pitts; Herbert A. Wolff, R. R. Donnelly and Sons Company; and Henry C. Woods, Sahara Coal Company.

Zwiener Opens Meeting

The meeting opened with introductory remarks by Kenneth V. Zwiener, president, Harris Trust and Savings Bank, Chicago, who is chairman of Mayor Richard Daley's Air Pollution Committee in Chicago.

Three papers on air pollution in the greater Chicago area were presented before the meeting adjourned for lunch. Morris A. Fisher, supervisor of fine particles research, Armour Research Foundation, discussed "Major Provisions of Chicago's New Air Pollution Control Ordinance." "What the New Air Pollution Control Ordinance Means to Chicago's Department of Air Pollution Control" was delivered by Fred T. Mommsen, assistant director, Department of Air Pollution Control, Chicago.

A third paper entitled "The Proposed Zoning Ordinance for Cook County" was read by Erwin E. Schulze, newly elected member of MAPPA's board of directors, and chairman of APCA's Legal Committee.

Luncheon speaker was APCA's executive secretary Arnold Arch.

Personalia

Albert Locuoco—recently appointed head of Bureau of Industrial Air Pollution, Division of Air Pollution Control, Department of Public Health and Welfare, Cleveland, Ohio. The Cleveland Division of Air Pollution Control consists of three bureaus: Industrial Hygiene, Harold C. Cutter, Chief; Smoke Abatement, John L. Hodges, Chief; and Industrial Air Pollution. Commissioner of the Division is LeRoy Diehl. Mr. Locuoco was an aide on the air pollution control staff for 18 months. Previously, he was vice president in charge of research for the Center Chemical Corporation, and before that taught chemistry at John Carroll University.

* * *

Paul H. Goodell—well known in the field of industrial heating, has joined the Bettcher Manufacturing Corporation, Cleveland, Ohio as Chief Engineer. He is a member of the Oven and Furnace Standards Committee of the National Fire Protection Association and has authored technical papers on various phases of infrared and industrial heating, the latest being "Industrial Ovens Designed for Air Pollution Control." This was presented at APCA's annual meeting in Los Angeles last year. In his new position, Mr. Goodell will supervise research and product development functions relating to process and space heating equipment made by the Panelbloc Division of the Corporation.

(*Continued on page 95*)

★ ★ ★ Section Hi-Lights ★ ★ ★

Niagara Frontier Section

The January meeting of the NFS took place the 28th. Harry Belyea was the principle speaker. He gave the gathering at the Peace Bridge Motel, Buffalo "A Summary of the APC Activities of Metropolitan Toronto."

The new 1960 officers, elected in December, presided at the meeting. They are George Brandt, Socony Mobil Oil Company, Chairman; George Amery, E. I. du Pont de Nemours Company, Vice Chairman; Thomas Danforth, Danforth and Cunningham Associates, Secretary; Robert Kennedy, Olin Mathieson Chemical Corporation, Treasurer.

New England Section

The NES is in the process of planning their 1960 Annual Meeting. It will take place in the Spring. The program has not as yet been decided upon. In the past, the Section scheduled papers on each of the following subjects: combustion of solid fuels, odor control, radioactive disposal problems, and a report of a research investigation or field survey of air pollution from a single or multiple source. The Section is also considering the possibility of scheduling a "single interest" program along the lines of radioactive air pollution, planning and analyzing air pollution surveys, air pollution control equipment, or applications and functions.

West Coast Section

1960 officers for the WCS are as follows: Chairman, Gerald Fisher; Vice Chairman, Dale H. Hutchison; Secretary-Treasurer, Robert G. Lunche. The Executive Committee is Warren R. Crouse, John H. Easthagen, and George J. Taylor.

* * *

The Bay Area dinner meeting held November 20, 1959, featured a panel discussion on "Proposed Standards for Air Quality and Automobile Exhaust Emissions in California." Participants were John A. Maga, Chief of the Bureau of Air Sanitation, California Department of Public Health, who discussed the standards; Benjamin Linsky, Bay Area Air Pollution Control District Officer, who discussed the effect that the standards may have on local control programs; and Assemblyman W. Byron Rumford, Chairman of the Assembly Interim Committee on Public Health and the author of the bill requiring air quality standards, who discussed the political implications of the proposed standards.

East Central Section

The ECS officers for 1960 are Walter I. Rauh, chairman; Morton Sterling, vice chairman; and D. H. Matheson, Secretary-Treasurer. The Section is looking forward to an active year and hopes to see a greater attendance at its meetings. It would especially like to see more people from south of Kentucky.

MEETING TO BE HELD

The Air Pollution Control League of Greater Cincinnati will hold its 54th Annual Meeting February 17 in Cincinnati. It was incorporated in 1906 for the purpose of abating the smoke nuisance by conducting an intensive, continuous public educational program for air sanitation.

The League is a citizens' organization which works continuously to advance the knowledge and practice of air pollution control throughout the metropolitan area. It is one of the original charter agencies of the Community Chest, from which it receives the major portion of its financial support.

Arnold Arch, APCA's executive secretary, will be a speaker at the meeting.

(*Continued from page 94*)

that Dr. Greenburg has made a substantial contribution in his service to the city. As a medical man as well as engineer he enlarged public understanding of what air pollution really is. It is far more than black smoke. He set up a laboratory, for the scientific approach, to analyze the content of the air. He educated the public to the concept that air pollution is a health problem, not merely a nuisance. He enlarged the horizon as to the full scope of the task, and its import.

Along with most other large cities New York is more conscious today of the need for air pollution control than it was a decade ago. So we were surprised recently to hear a suggestion that the city's department be abolished, and the function put back, as a subsidiary, into another department. It was the enforcement failure induced by just such minimization of the importance of control that resulted in creation of the independent agency we have today.

Dr. Greenburg could have been a more complete success if he hadn't been underbudgeted, undermanned throughout his tenure. He was trying to police air pollution in a city of 319 square miles with about forty inspectors. It can't be done.

Personalia

(*Continued from page 94*)

George E. Best—recently joined the staff of the Manufacturing Chemists' Association as staff secretary to MCA's committees on air and water pollution abatement and chemical packaging as well as to handle special assignments. A graduate of the Massachusetts Institute of Technology, Mr. Best has had 20 years' experience in the chemical industry. He was a member of MCA's Air Pollution Abatement Committee from 1949 to 1955, and was active in the preparation of their publication "A Rational Approach to Air Pollution Legislation."

* * *

Richard A. Wolff—assumed his duties as deputy commissioner of the New York City Department of Air Pollution Control recently. He has been a member of the New York Board of Air Pollution Control since its inception in 1953. He has a degree in mechanical engineering from Stevens Institute of Technology and has been a professional engineer in New York State since 1922. In 1951, he received a Certificate of Appreciation for Patriotic Civilian Service from the Department of the Army. During part of World War II, Commissioner Wolff served as a member of the Technical Industrial Intelligence Committee, Joint Chiefs of Staff, in addition to helping organize the Office of Production Research and Department of the War Production Board in Washington, D. C.

* * *

George F. Collins—has joined the Lockheed Aircraft Corporation as an Associate Scientist in the Meteorological Research Department. This is a newly organized group providing research and consultation in micrometeorology, applied climatology, weather forecasting, and oceanographic meteorology to industry and others. One of the fields in which they hope to be active is air pollution abatement. Mr. Collins was formerly with the DuPont Company.

(*Continued from page 59*)

with the responsibility to dispose of waste materials would first ask themselves, "What effect will a disposal process have upon the air of our community?" If the question cannot honestly be answered "that the disposal process will have little or no effect upon the atmosphere," then it behooves engineers to dig deeper into their store of engineering ability and come up with answers which will meet that simple criteria.

Nominate Your Award Candidate

The Awards Committee, James H. Carter, chairman, is still requesting nominations for the Frank A. Chambers and Richard Beatty Mellon Awards, and Honorary Memberships. Your nominations should be sent to: James H. Carter, Smoke Commissioner, City of St. Louis, Room 419 City Hall, St. Louis, 3, Missouri.

Frank A. Chambers Award

This award was established by resolution of the Board of Directors on February 12, 1954, to be awarded to an individual "for outstanding achievement in the control of air pollution." It may be awarded to members or nonmembers of APCA.

Eligibility for this award requires a specific act on the part of the recipient which is considered to be a major contribution to the science of air pollution control. It is not awarded for general excellence of work or prominence in the field.

Frank A. Chalmers (1885–1951) was a founder of the Smoke Prevention Association of America, forerunner of APCA, and almost singlehandedly established the foundation of our present Association. His ideas have been put into operation in many cities in the United States.

Richard Beatty Mellon Award

This award is given to the individual "whose contributions of a civic, administrative, technical or other nature have aided substantially the cause of air pollution control." It may be awarded to members or nonmembers of APCA.

Eligibility for the award requires the sincere and constant effort of an individual over a period of time to develop or increase interest in or acceptance of the cause of air pollution control. It is awarded to that individual who, through unselfish interest and in a manner best suited to his own resources has furthered the cause of air pollution control.

Richard Beatty Mellon (1858–1933), in the desire to benefit mankind, with his brother Andrew William Mellon, established the Mellon Institute of Industrial Research in 1913. Mr. Mellon showed great interest in the abatement of urban smoke and air pollution. He was the leader in incepting and sustaining the first modern investigations looking to ways and means for controlling the pollution of our atmosphere.

Honorary Memberships

Honorary memberships are conferred on persons "of widely recognized eminence in some part of the field of air pollution control which the Association aims to cover," or who have "rendered especially meritorious service to the Association." This may be conferred on members or nonmembers of APCA.

How to Nominate Candidates

1 Your nomination, in the form of a letter, shall contain:
   - *a* The full name, address and business affiliation, including title, of the nominee;
   - *b* Designation of the Honor or Award for which he is being nominated;
   - *c* A concise and explicit statement of the attainment or achievement which, in your opinion, entitles the nominee to the award. (This may form the basis for a citation and care should be given to its preparation.);
   - *d* A brief biography of the nominee;
   - *e* Any additional information which you may feel may assist the Awards Committee in arriving at a decision.

2 Nominating letters shall contain:
   - *a* For Honorary Membership, a minimum of twenty-five (25) signatures of members of the Association;
   - *b* For the Frank A. Chambers and Richard Beatty Mellon Awards, the names of at least three (3) persons who have first-hand knowledge of subject matter requested in 1 (c).

3 Letters of nomination will be accepted from nonmembers as well as members of APCA. Be sure to state whether the nominee is sponsored by you individually, or by an organization you represent.

4 Nominations shall be received by the Awards Committee not later than April 1, to be considered at the next annual meeting.

Next Issue . . .

The April issue of the JOURNAL will feature a number of articles on the flue-fed incinerator which were given at the Los Angeles meeting. In addition, a number of APCA committee reports will be published.

An extra feature will be the publication of parts of a thesis done at the Wharton School of Finance and Commerce, University of Pennsylvania, on "Industrial Responsibilities In and Advantages From the Control of Air Pollution."

APCA's TI-2 Committee on Chemistry will report on "The Chemical Industry's Air Pollution Problems."

APCA History Included

Also, at long last, it is hoped that the APCA History, by William G. Christy, will appear in the April issue. In the process for a number of years, it chronicles APCA's rise from a small organization to its position as a leader in air pollution matters today.

The papers on flue-fed incinerators will include:

1 Controlling the flue-fed incinerator;
2 Modifications to reduce emissions from a flue-fed incinerator;
3 Attitudes on the design of flue-fed incinerators;
4 Effects of design and fuel moisture on incinerator effluents;
5 Bench-scale investigation on removing sulfur dioxide from flue gases.

Many other interesting and informative articles will appear in the coming issue.

"The Fallout Problem" and "The Smogless Automobile" are two. Also "Performance Standards in Zoning Ordinances" will be featured.

With the Annual Meeting fast approaching, look for a spread on Cincinnati, the site for the coming event. A tentative program of the Annual Meeting will be available for printing. There will be lots to interest you, so be on the lookout in April.

Classified

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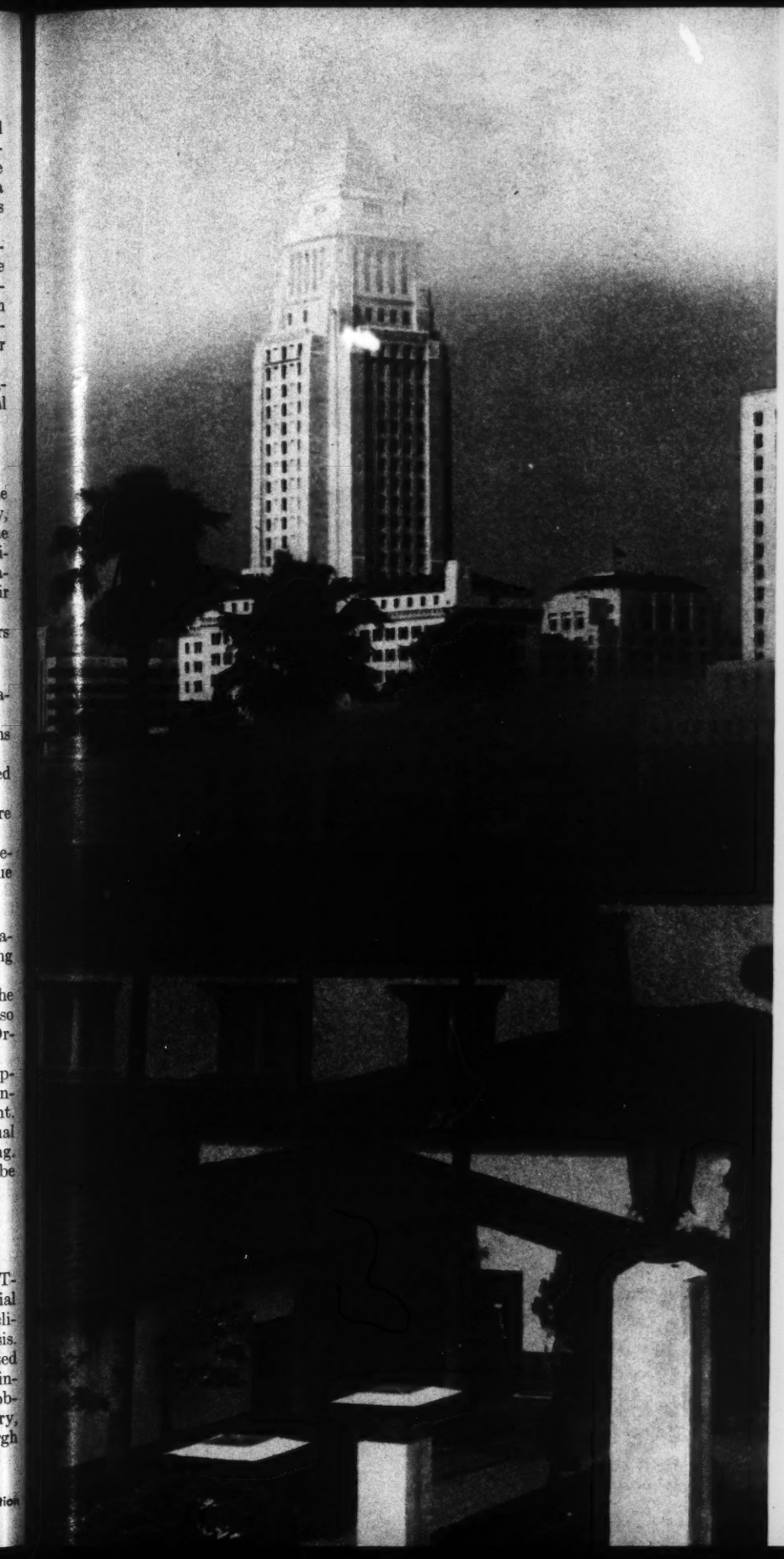

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